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This book is designed to give the automotive emissions control inspector the technical and background knowledge needed to perform a satisfactory emissions inspection on an automobile. This is, however, limited to taking an exhaust sample and reading the results on an emissions analyzer. The background material contained is basic general information and should be used only to help the inspector to acquire a job entry level of proficiency.

These instructional materials provide the inspector with technical information on emissions control systems and related narratives on the infrared analyzer. It should also provide him with the basic information needed to understand the concepts of the various emissions control systems presently on automobiles.

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Nov 77

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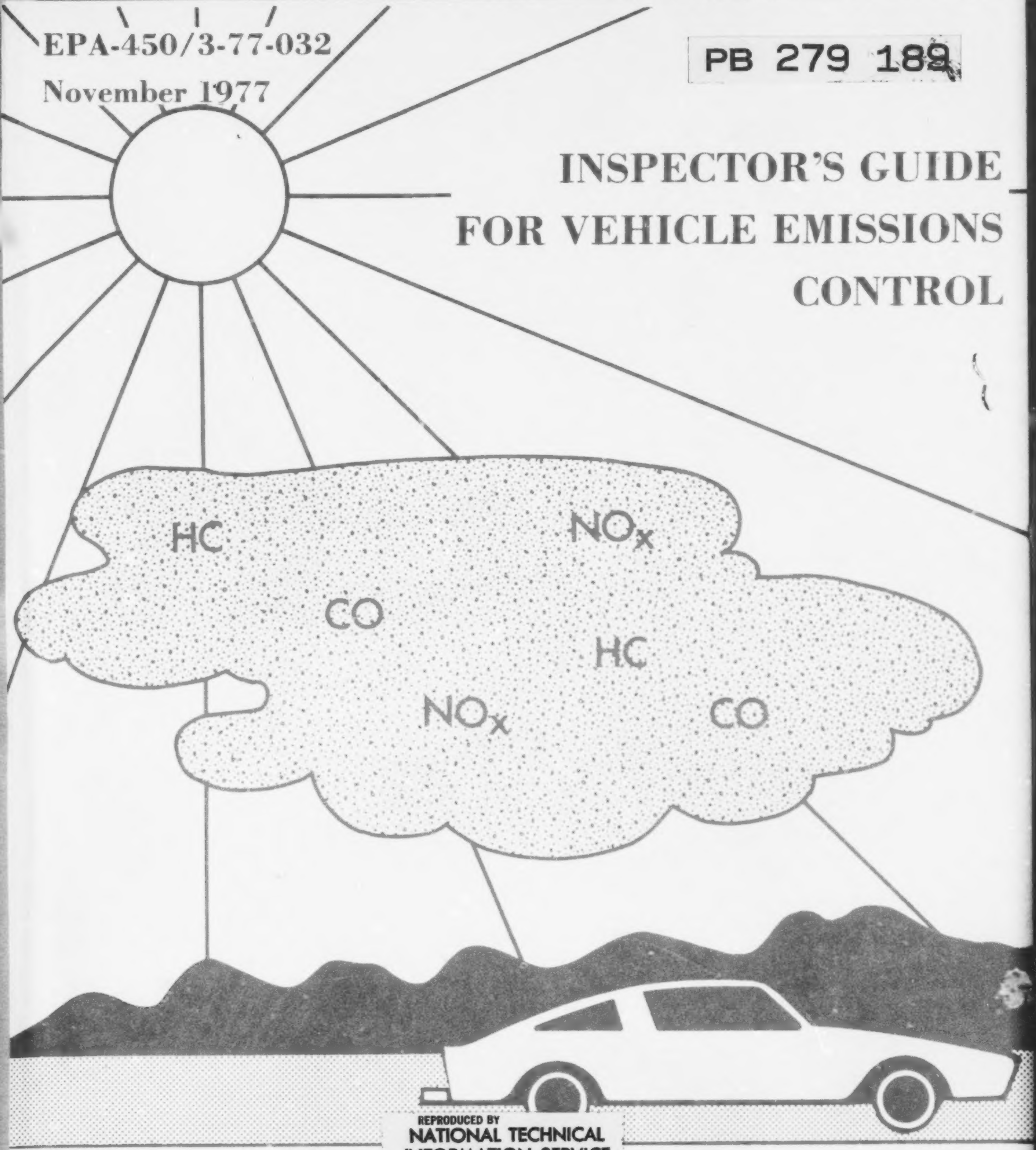
INSPECTOR'S GUIDE FOR VEHICLE EMISSIONS CONTROL



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Research Triangle Park, North Carolina 27711

EPA-450/3-77-032

INSPECTOR'S GUIDE FOR VEHICLE EMISSIONS CONTROL

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Control Programs Development Division
Research Triangle Park, North Carolina 27711

November 1977

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Publication No. EPA-450/3-77-032

INTRODUCTION

The objective of this material is to give the automotive emissions control inspector the technical and background knowledge needed to perform a satisfactory emissions inspection on an automobile. This is, however, limited to taking an exhaust sample and reading the results on an emissions analyzer. This material does not contain the standards set by state or federal government. The background material contained herein will provide the inspector with basic general information about automotive emissions and automotive emissions controls. It is in no way conclusive and should be used only to help the inspector acquire a job entry level of proficiency.

The overall objectives of this packet are to provide the basic knowledge needed to inspect a vehicle for motor vehicle emissions control. Since passage of the Clean Air Act, much emphasis has been placed on automotive emissions control devices. It is important that the emissions inspector have a basic understanding of these devices, their purposes, and functions to provide meaningful dialogue to the automobile owner as questions arise.

These instructional materials provide the inspector with technical information on emissions control systems and related narratives on the infrared analyzer. The knowledge gained by studying this material should provide the inspector with the basic information needed to understand the concepts of the various emissions control systems presently on automobiles. It should also provide a basic understanding of the cause of vehicle emissions and a basic understanding of how the infrared analyzer is used to determine the amount of HC and CO emissions produced by a vehicle. Proficiency on the use of the analyzer can be gained only through experience.

A gaseous ghost named VEC (Vehicle Emissions Control) is used in many of the illustrations. This method of presentation is used to visually emphasize points which are basic and considered important for an understanding of the concept.

ASSUMPTIONS

The following assumptions were made in the development of this material.

1. These materials are designed for inspector's use.
2. The inspector will not necessarily have to do any repair work.
3. The inspector will have state and/or federal emissions standards available.
4. The inspector will have the necessary rules and regulations governing emissions inspection for that particular area in which he is working.
5. The inspector may provide advice to the vehicle owner concerning possible causes for the failure of an automobile and actions that need to be taken to correct identified problems.
6. The inspector will have had proper instruction on the use, calibration and maintenance of the exhaust gas analyzer and have the proper instruction book for the analyzer.

ACKNOWLEDGMENTS

The Motor Vehicle Emissions Control Staff of the Department of Industrial Sciences at Colorado State University would like to acknowledge the efforts extended by the Environmental Protection Agency, Research Triangle Park, for their contributions to the development of this booklet.

A special thanks must be extended to the automotive vehicle equipment and parts manufacturers for their cooperation and assistance in the development of this training material.

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NOTICE

This document is currently being revised to incorporate additional information and techniques that are considered to be desirable. The present volume will, however, prove to be a valuable guide until the next edition becomes available.

CHAPTER 1

THE CAUSE AND EFFECT OF AUTOMOBILE EMISSIONS

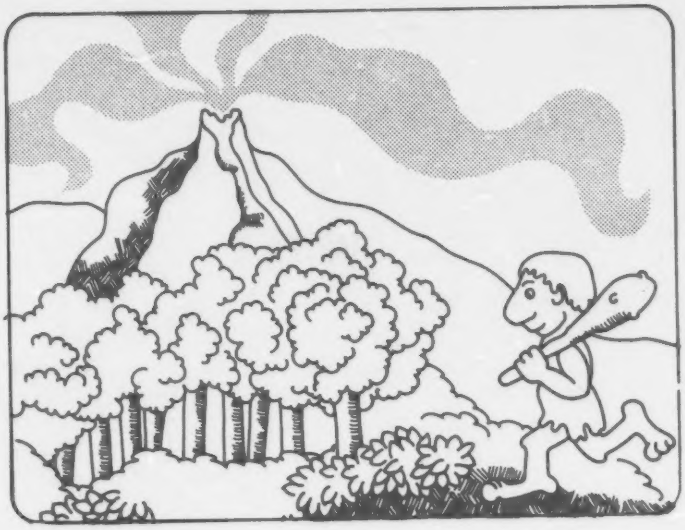

FIGURE 1-1

Perfectly pure air, containing approximately 78% nitrogen, 21% oxygen and 1% other inert, harmless gases, is very rare today and probably has been very rare for many centuries. Air pollution has always existed in one form or another. In nature it has come from volcanoes, decaying vegetation as well as our forest of evergreen trees. This type of air pollution is a product of nature and there is no known way we can control it.

The types of air pollution we can control are the ones that we cause. One of these, in particular, is the pollution from automobiles. It has been said that the automobile contributes heavily to the total pollutants caused by man. Approximately one-half of the total hydrocarbons (HC), more than three-quarters of the total carbon monoxide (CO) and nearly one-half of the oxides of nitrogen (NO_x) emissions come from automobiles. (See Figure 1-2.) This is a significant contribution.

Another problem is that most of this contribution is made in larger cities where the majority of people and automobiles congregate (Figure 1-3). The very design of cities with their tall buildings and relatively narrow streets tends to limit air movement which traps and concentrates these pollutants. This is one reason why levels of certain pollutants climb above safe maximum limits.

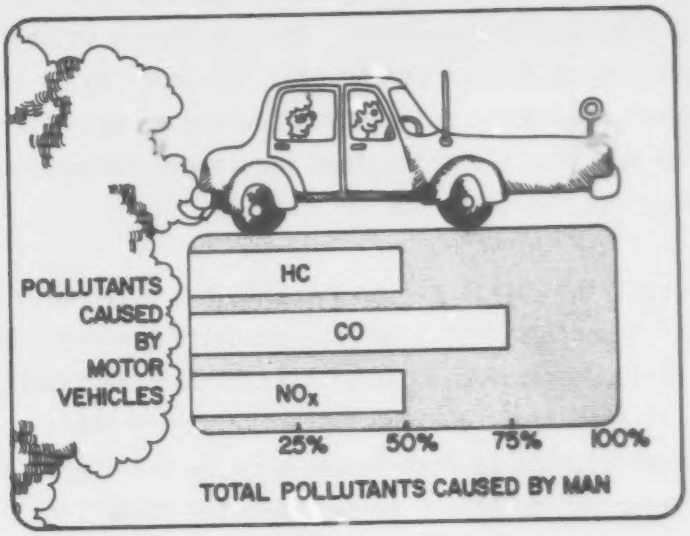

FIGURE 1-2

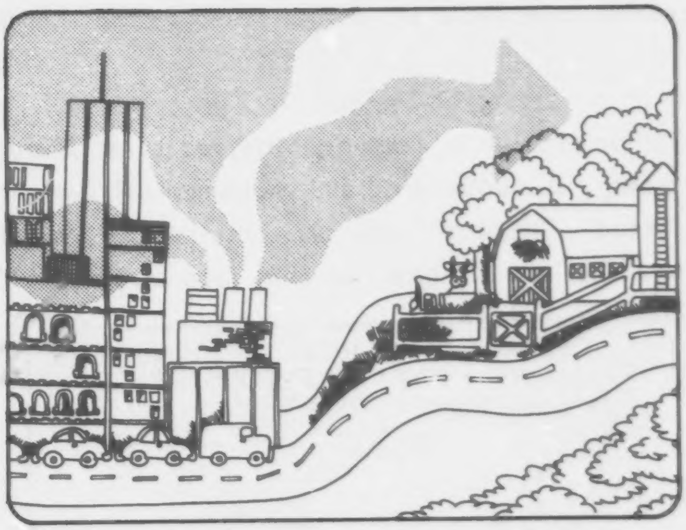

FIGURE 1-3

The problem, however, does not stay just in the cities and the surrounding urban areas. It can be moved great distances by atmospheric conditions such as the wind. Pollutants have been detected in towns forty to one hundred miles from major metropolitan areas. These towns, although far removed from the cities, actually exceed the same safe limits for certain pollutants.

The Environmental Protection Agency (EPA) has been assigned the job of establishing air quality standards. The standards, established by the EPA, are designed to protect our health. In order to do this, the EPA and the federal government deemed it necessary to establish limits for the amount of pollutants emitted from stationary and mobile sources. The largest mobile source is the automobile.

In order to meet the limits set by the EPA, the automobile manufacturers had to redesign parts of the internal combustion engine. They also had to develop various emissions control systems for the internal combustion engine. It is important that the inspector have a basic knowledge of these emissions systems so that he can provide meaningful dialogue to the automobile owner as questions arise about the inspection process and corrective measures.

Let's look at some of the air pollution problems that are being talked about and examine some cause and effect relationships concerning the automobile.

SMOG

One air pollution problem is commonly referred to as "smog." There are two types of smog, sulfurous smog and photochemical smog. Both of these will be discussed. The word "smog" was originally formed from two words, smoke and fog. The correct name for this type of smog is "sulfurous smog."

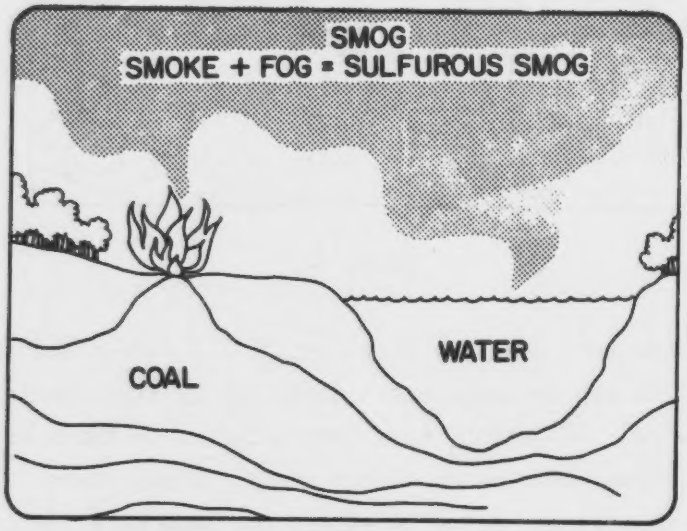

FIGURE 1-4

As its name suggests, it is a combination of sulfur-bearing pollutants. Sulfur is found in all fossil fuels, whether they are coal or oil. This type of air pollution has been known for over 600 years. The automobile's contribution to this type of smog is negligible.

Photochemical smog, however, is related to the automobile. Photochemical or "Los Angeles" type smog results from hydrocarbons (HC) and oxides of nitrogen (NO_x) changing chemically in the presence of sunlight (Figure 1-5).

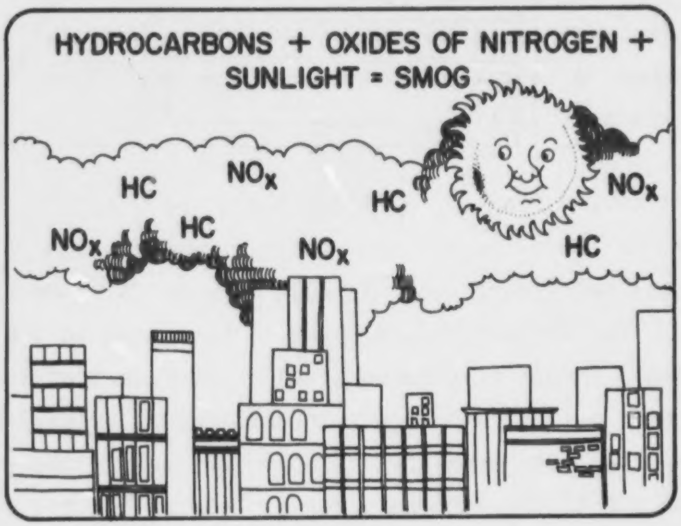
HYDROCARBONS + OXIDES OF NITROGEN + SUNLIGHT = SMOG
HC
NO_x
HC
NO_x
NO_x
HC
NO_x
HC
NO_x
HC

FIGURE 1-5

One main source of these hydrocarbons and oxides of nitrogen is the internal combustion engine found in motor vehicles.

CAUSE OF HYDROCARBON EMISSIONS

Motor vehicles use gasoline, a petroleum product, for fuel. Gasoline, like all petroleum products, is comprised of hundreds of hydrocarbon compounds. In the internal combustion engine, 100% or complete combustion does not occur. Consequently, some unburned hydrocarbons are exhausted to the atmosphere. One of the causes of unburned hydrocarbon emissions is a phenomenon called "quenching" (Figure 1-6). Quenching is what happens to a flame in the combustion chamber as it approaches the relatively cool metal surfaces. The flame does not burn right up next

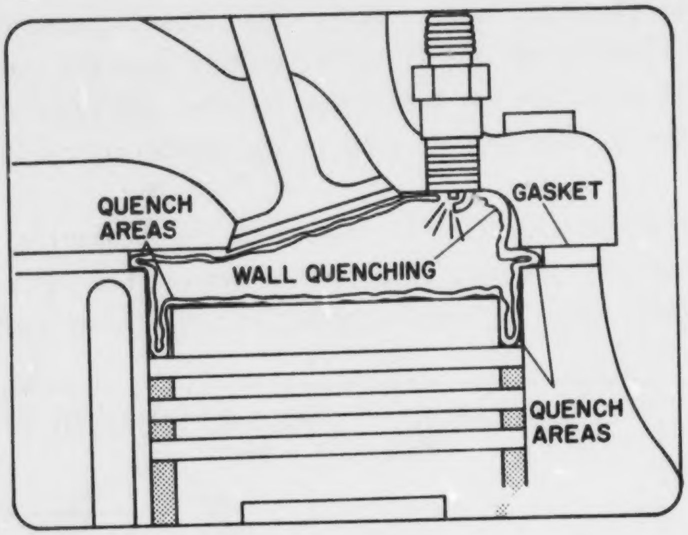

FIGURE 1-6

to these cool metal surfaces. It goes out, or is "quenched" by these cool areas. The failure of the flame to burn next to the metal surfaces leaves a small amount of unburned fuel or hydrocarbons in this area. This quenching action also occurs in small areas or cavities in the combustion area. One such area is where the head gasket seals the cylinder head to the block. Another area is between the top of the piston and the first compression ring. Since the flame does not burn into these areas, there is a small amount of unburned fuel from each area that is exhausted to the atmosphere.

Another cause of unburned hydrocarbons is due to combustion chamber deposits (Figure 1-7). These deposits are porous. As the piston comes up on the compression stroke, some fuel is forced into these deposits. This absorbed fuel never burns, but comes out of these deposits late in the power stroke, or during the exhaust stroke, and is discharged to the atmosphere on the exhaust stroke.

Quenching and combustion chamber deposits are not the only cause of unburned hydrocarbons. The ignition system can cause a significant increase in hydrocarbon emissions. If any part of the ignition system,

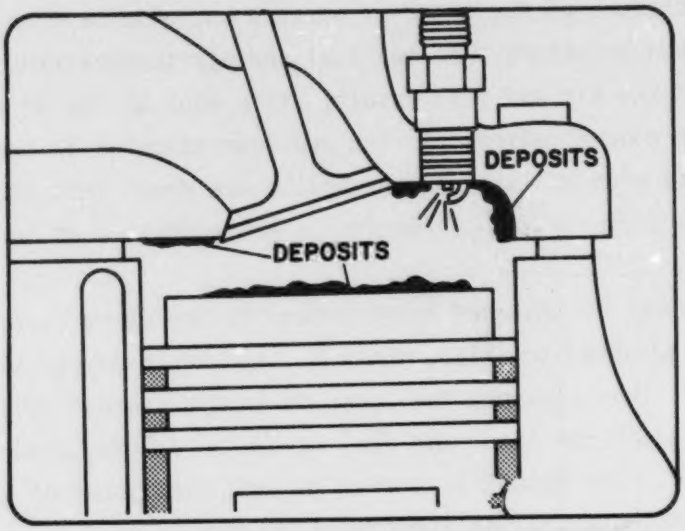
DEPOSITS
DEPOSITS

FIGURE 1-7

such as the points, becomes worn or out of adjustment the result could be a weak spark or no spark at all. This will lead to either incomplete combustion or a misfire. Either condition will result in the emissions of unburned hydrocarbons (Figure 1-8).

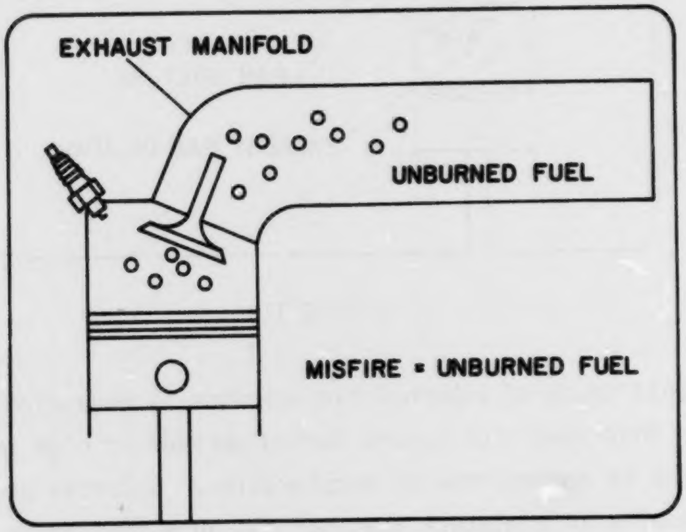
EXHAUST MANIFOLD
UNBURNED FUEL
MISFIRE = UNBURNED FUEL

FIGURE 1-8

The temperature of the air/fuel mixture can also have an effect on unburned hydrocarbon emissions. If the fuel and air temperatures are low, poor mixing of the air and fuel result. This poor mixing of air and fuel can result in concentrations of rich and lean mixtures in the intake manifold. When these rich or lean concentrations are drawn into the cylinder, they do not burn evenly. This results in the emissions of unburned hydrocarbons.

Another cause of unburned hydrocarbons is the carburetor. If the carburetor is adjusted too rich, there is not enough oxygen to completely burn the fuel. This unburned fuel results in hydrocarbon emissions. If the mixture is set too lean, the fuel may be so diluted with air that it will not ignite. The result is a misfire, and the amount of fuel that did not burn is exhausted to the atmosphere (Figure 1-9).

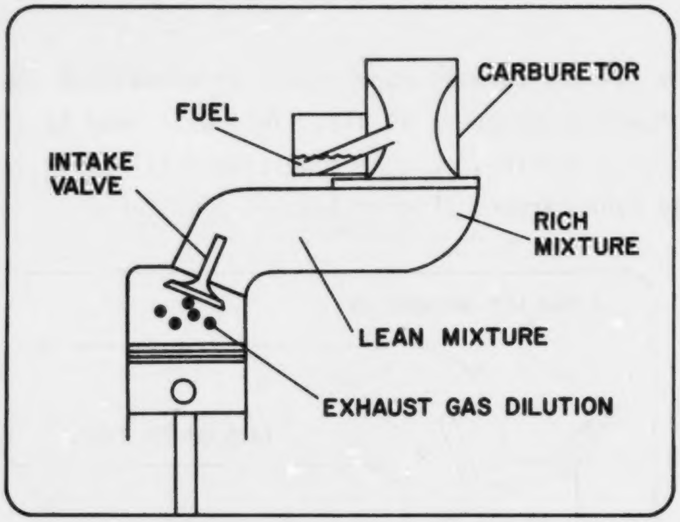

FIGURE 1-9

An additional cause of unburned hydrocarbons is excessive exhaust gas dilution. This condition occurs during periods of high intake manifold vacuum, such as engine idle or deceleration. Dilution of the air/fuel mixture results in a mixture that may not burn completely or may cause a complete misfire.

EFFECTS OF HYDROCARBON EMISSIONS

One effect of hydrocarbon emissions has already been mentioned. That is the chemical combustion of hydrocarbons and oxides of nitrogen in the presence of sunlight which results in photochemical smog. Some of the unburned hydrocarbons that are emitted are very chemically active. Some combine with oxides of nitrogen and form photochemical smog. Others remain in the air and act as an irritant to the eyes (Figure 1-10).

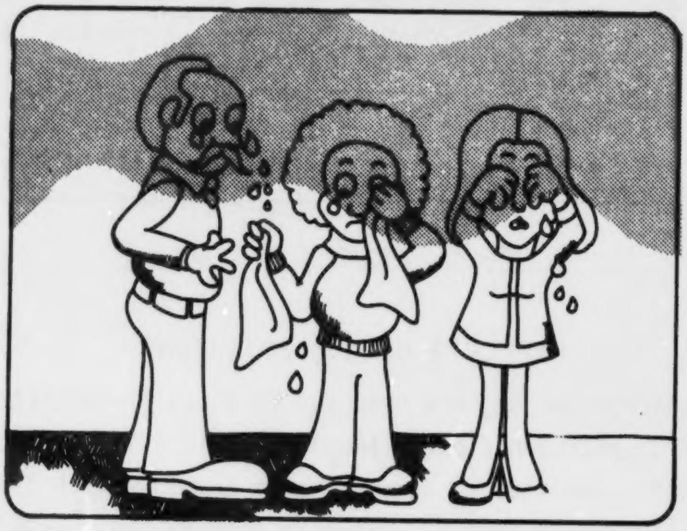

FIGURE 1-10

These are the heavier hydrocarbons or the aromatics. One of these heavier hydrocarbons, benzo-a-pyrene, is also suspected of being a cancer-causing agent or a carcinogen.

CAUSE OF NO_x EMISSIONS

Another pollutant the automobile emits is NO_x or oxides of nitrogen. Air is made up of approximately 78% nitrogen, 21% oxygen and 1% of other gases. This air is drawn into the engine and mixed with fuel. This air/fuel mixture is ignited and temperatures in excess of 4500°F may be reached. At temperatures above approximately 2500°F, nitric oxide (NO) is formed very rapidly from the nitrogen and oxygen in the air. The formation of nitric oxide (NO) is dependent on temperature. Any engine variable that causes an increase in temperature above approximately 2500°F will cause an increase in nitric oxide (NO) emissions (Figure 1-11).

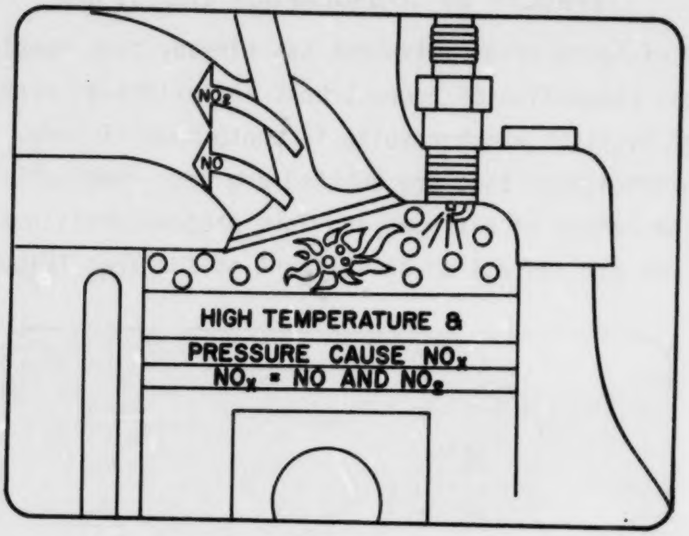

FIGURE 1-11

EFFECTS OF NO_X EMISSIONS

Oxides of nitrogen or NO_x are composed of about 97-98% nitric oxide (NO) and about 2-3% nitrogen dioxide (NO_2). Nitric oxide is a colorless gas, but when it is exhausted to atmosphere it combines with oxygen (O_2) and forms nitrogen dioxide (NO_2). Nitrogen dioxide (NO_2) is a brownish color. The nitrogen dioxide (NO_2) then combines with certain chemically active hydrocarbons in the presence of sunlight and causes the formation of photochemical smog.

Some of the nitrogen dioxide is broken apart by sunlight to form nitric oxide and oxygen ($NO_2 + \text{sunlight} \longrightarrow NO + O$). This single oxygen (O) atom combines with diatomic oxygen (O_2) to form ozone (O_3). Ozone, an odorous gas, is one of the smells associated with smog. Ozone also acts as an irritant to the lung tissues and the eyes. Ozone also deteriorates rubber products rapidly, and affects the growth of some crops and plants (Figure 1-12).

CAUSE OF CARBON MONOXIDE EMISSIONS

Carbon monoxide is another pollutant that originates in the combustion process. Carbon monoxide (CO) is formed when there is not enough oxygen

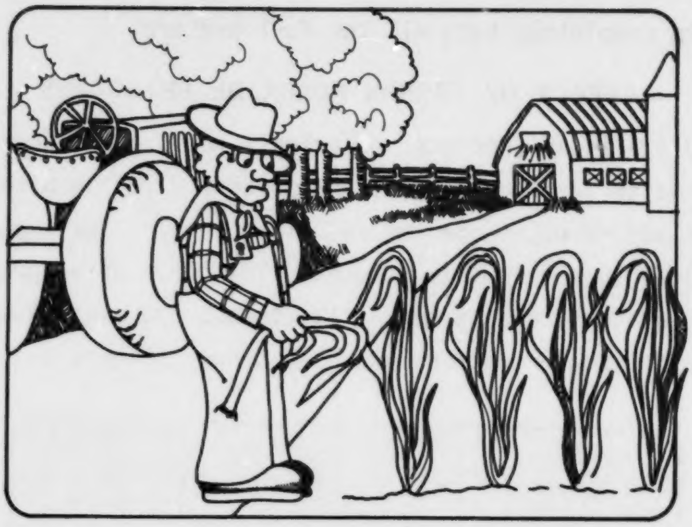

FIGURE 1-12

present to convert carbon (C) to carbon dioxide (CO_2). As the air/fuel ratio becomes richer than approximately 15:1, there is not enough oxygen present to complete the combustion process (Figure 1-13). This shortage

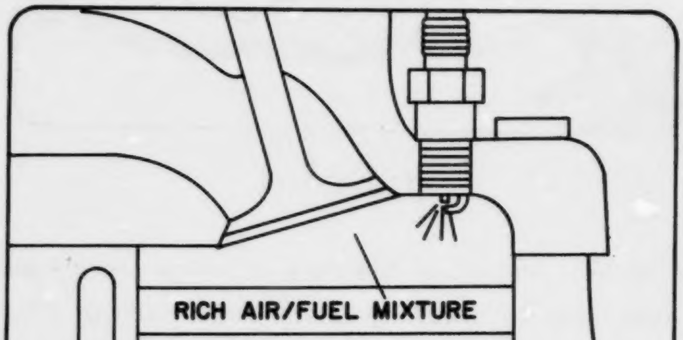

FIGURE 1-13

of oxygen results in an incomplete conversion of carbon (C) to carbon dioxide (CO_2). An increase in CO emissions is normally accompanied by an increase in HC emissions. This is because of the lack of oxygen necessary to completely burn all the fuel mixture.

EFFECT OF CARBON MONOXIDE EMISSIONS

Carbon monoxide is an odorless, colorless, toxic gas. When carbon monoxide is inhaled into the lungs and transferred to the blood stream, it takes the place of oxygen in the red blood cells. The amount of oxygen being supplied to the body is reduced. This lack of oxygen to the body can cause headaches, reduce mental alertness, and even cause death if carbon monoxide concentrations are high enough (Figure 1-14).

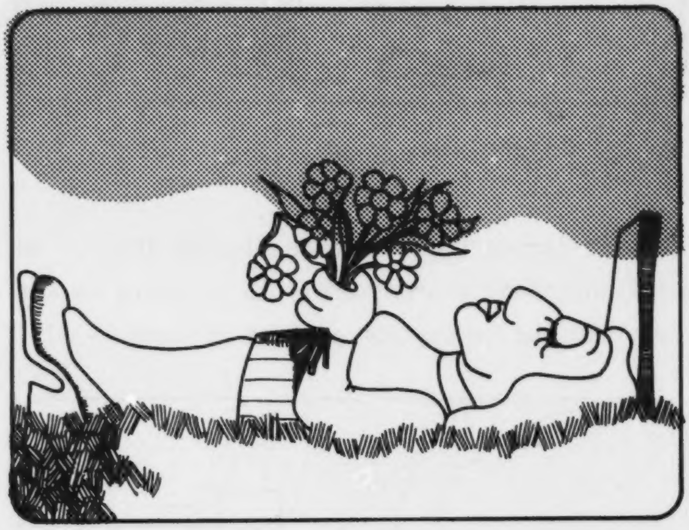

FIGURE 1-14

Carbon monoxide also increases the rate at which photochemical smog is formed. It does this by speeding up the conversion of nitric oxide (NO) to nitrogen dioxide (NO_2). Carbon monoxide (CO) speeds up this reaction by combining with oxygen (O_2) and nitric oxide (NO) to produce carbon dioxide (CO_2) and nitrogen dioxide (NO_2) ($CO + O_2 + NO \longrightarrow CO_2 + NO_2$).

CAUSE OF PARTICULATE EMISSIONS

Particulate emissions also come from the automobile engine. Although there is no limit for particulates at the present time, they are worth discussing. Particulate emissions result primarily from hydrocarbon fuels and certain fuel additives. The carbon particulates originate from the tetra ethyl lead $Pb(C_2H_5)_4$ that is added to the fuel to raise the octane rating (Figure 1-15).

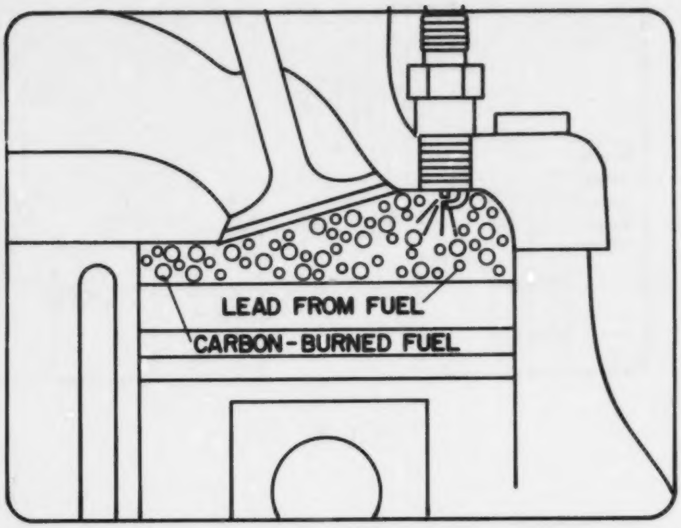

FIGURE 1-15

EFFECTS OF PARTICULATE EMISSIONS

Small particulates that are suspended in the atmosphere are one of the causes of the reduced visibility that accompanies photochemical smog. Lead particulates that are emitted to the atmosphere are suspected of being a health hazard in two ways: (1) respiratory intake of airborne lead during breathing and (2) contamination of food by lead that has settled in the soil (Figure 1-16).

CAUSE OF SO_X EMISSIONS

Another air pollution problem has recently been discovered. This is the problem of oxides of sulfur (SO_X) emissions. This problem became evident with the introduction of catalytic converters. Oxides of sulfur result from the small amount of sulfur present in gasoline. Normally, the sulfur content of gasoline is less than 0.1%. However, this small amount of sulfur is emitted from the engine exhaust to the atmosphere (Figure 1-17).

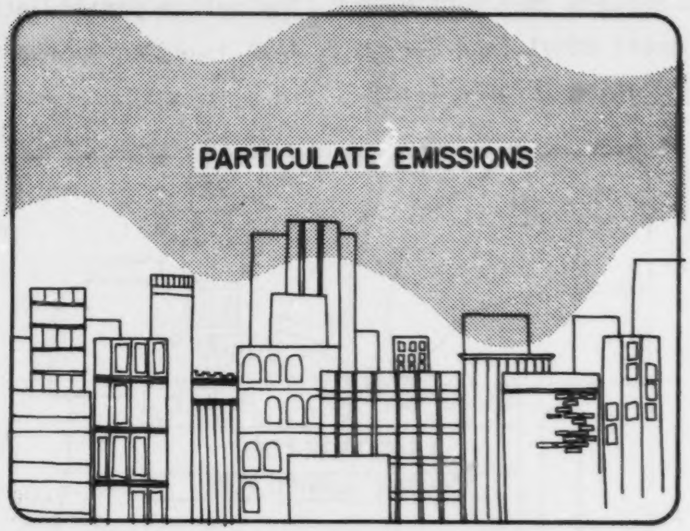
PARTICULATE EMISSIONS

FIGURE 1-16

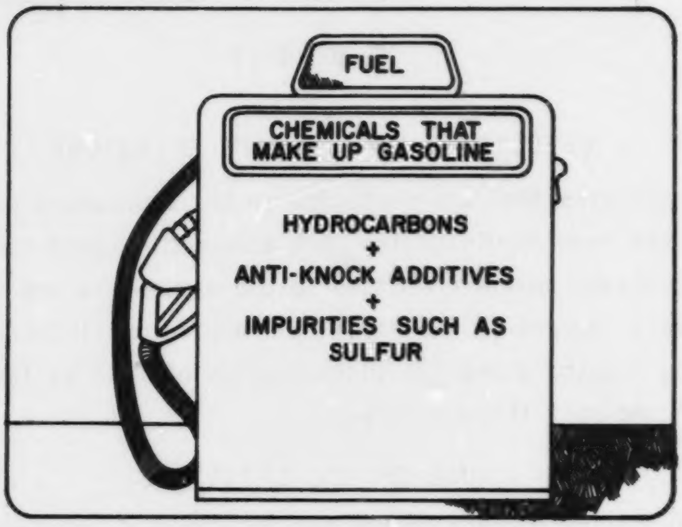
FUEL
CHEMICALS THAT MAKE UP GASOLINE
HYDROCARBONS
+
ANTI-KNOCK ADDITIVES
+
IMPURITIES SUCH AS SULFUR

FIGURE 1-17

EFFECT OF SO_X EMISSIONS

The major problem with SO_x emissions in motor vehicles is the production of a sulfuric acid mist. The problem occurs primarily from vehicles equipped with catalytic converters. These converters provide an oxidizing atmosphere that enhances the formation of sulfuric acid from the sulfur compounds in the fuel. In the catalytic converter, sulfur dioxide (SO_2) is converted to sulfur trioxide (SO_3) in the oxidizing atmosphere of the converter ($2SO_2 + O_2 \longrightarrow 2SO_3$). Sulfur trioxide ($SO_3$) combines with water ($H_2O$ vapor, the water vapor coming from the oxidation of hydrocarbons), and forms a sulfuric acid (H_2SO_4) mist. Sulfuric acid is very corrosive. Consequently, it will deteriorate textiles, building materials and vegetation. It is also very harmful to living tissue (Figure 1-18).

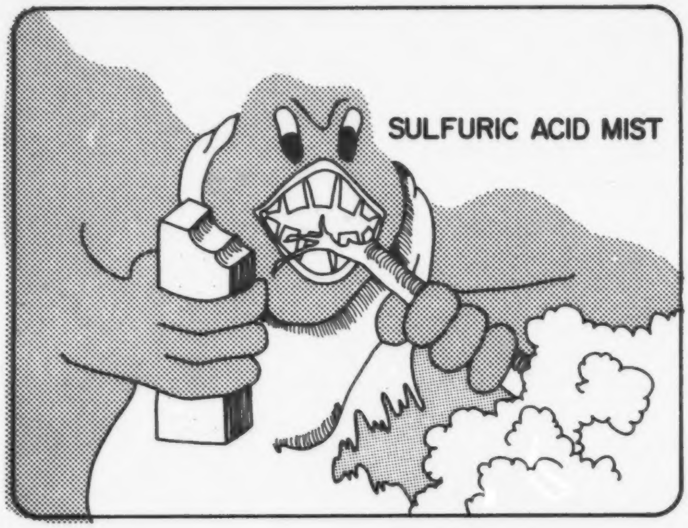

FIGURE 1-18

CHAPTER 2

POSITIVE CRANKCASE VENTILATION

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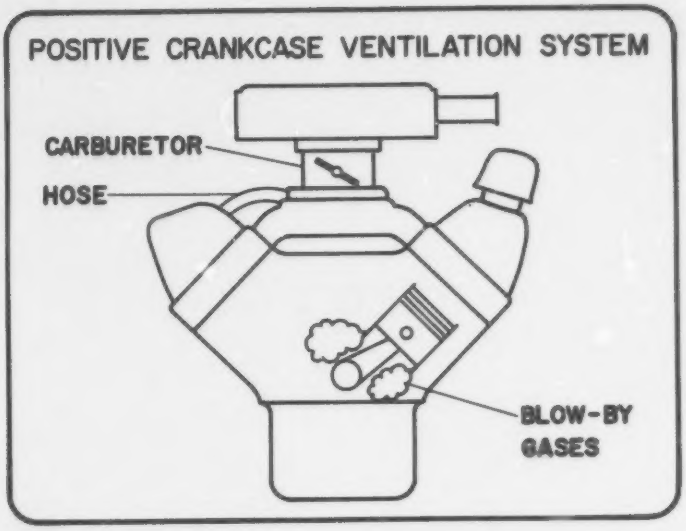

FIGURE 2-1

The crankcase ventilation system was the first antipollution device installed on the automobile. This ventilation system is known by the letters PCV which stand for Positive Crankcase Ventilation. The PCV system is very dependable and efficient and requires a minimum of maintenance.

The function of the positive crankcase ventilation system is to prevent the escape of blowby products to the atmosphere.

During the combustion process higher pressures are developed in the combustion chamber. This high pressure results in leakage or blowby between the piston rings and the cylinder wall. This blowby occurs during the compression stroke as shown in Figure 2-2 and in the power stroke as shown in Figure 2-3.

Blowby gases contain gasoline vapor, hydrocarbons (HC), corrosive acids, and water. To prevent high crankcase pressure and blowby products from reacting with the engine lubricant, the engine must be equipped with a means of crankcase ventilation.

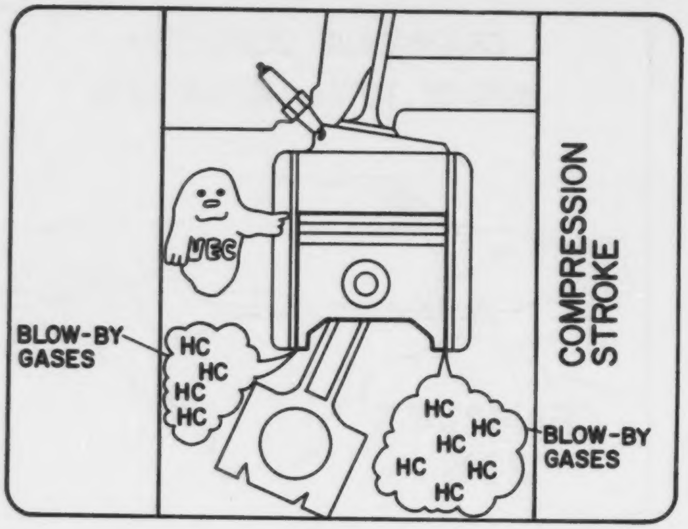
BLOW-BY GASES
HC
HC
HC
HC
HC
HC
HC
HC
HC
HC
BLOW-BY GASES
COMPRESSION STROKE
UEC

FIGURE 2-2

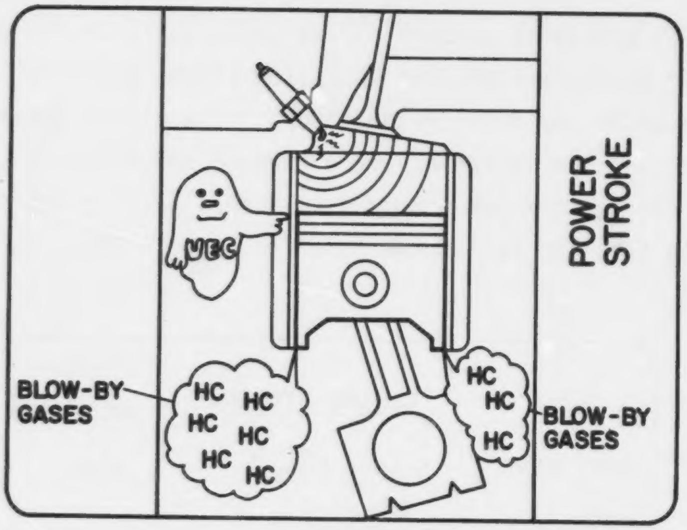
BLOW-BY GASES
HC
HC
HC
HC
HC
HC
HC
HC
HC
HC
BLOW-BY GASES
POWER STROKE
UEC

FIGURE 2-3

In pre-emissions control automobiles the blowby products were allowed to escape to the atmosphere through the open road draft tube. The resulting pollution from the crankcase amounted to approximately 20% of the total hydrocarbon (HC) pollution emitted by the automobiles (Figure 2-4).

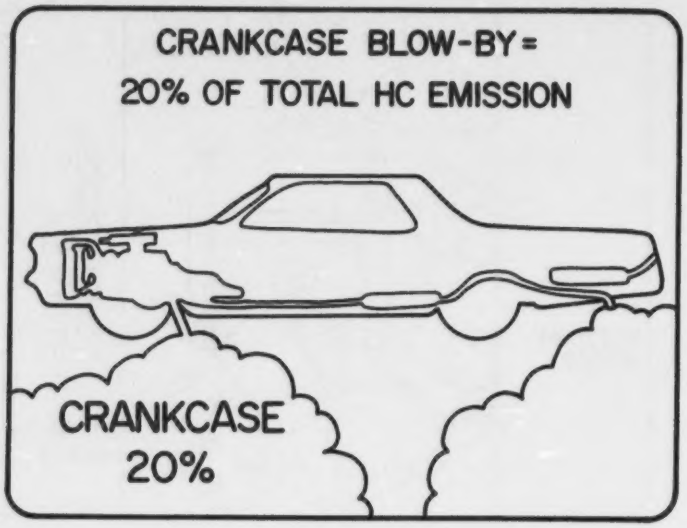
CRANKCASE BLOW-BY =
20% OF TOTAL HC EMISSION
CRANKCASE
20%

FIGURE 2-4

A closed PCV system is used on all vehicles built in the United States today. The closed system does not allow blowby gases to be emitted to the atmosphere under any driving conditions. The blowby gases are consumed by either entering the intake manifold through the PCV valve at the base of the carburetor or through a hose from the oil filler cap to the air cleaner and into the carburetor to be consumed. This system is shown in Figure 2-5.

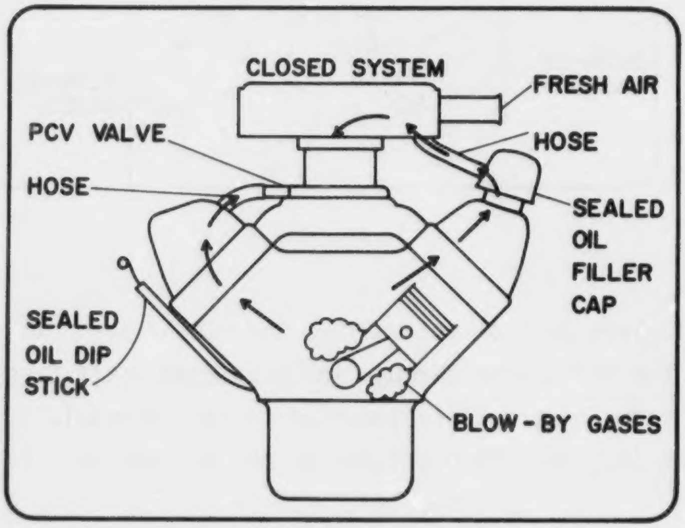
CLOSED SYSTEM
FRESH AIR
PCV VALVE
HOSE
HOSE
SEALED OIL FILLER CAP
SEALED OIL DIP STICK
BLOW-BY GASES

FIGURE 2-5

PCV valves are no longer serviceable but are simply replaced. All valves are identified by the manufacturer's number and in some cases, by a color code.

NEVED DISCONNECT OR PLUG THE PCV SYSTEM BECAUSE EVERY ENGINE NEEDS CRANKCASE VENTILATION. THE PRESSURE IN THE OIL PAN MUST BE RELIEVED ONE WAY OR ANOTHER.

Most domestic automotive manufacturers require that the system be inspected and the PCV valve be replaced at 12,000 to 30,000 miles as specified by the automobile manufacturer. This maintenance schedule can normally be obtained in the automobile owner's manual.

Remember - the PCV system reduces hydrocarbon emissions to atmosphere as well as preventing oil dilution and sludge formation in the crankcase. This is accomplished by directing blowby gases in the crankcase back to the combustion chamber to be burned.

CHAPTER 3

THERMOSTATIC AIR CLEANER

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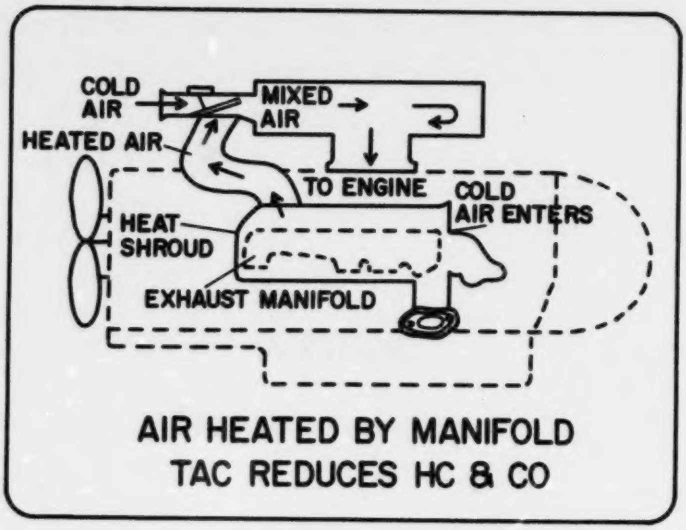

COLD AIR
MIXED AIR
HEATED AIR
TO ENGINE
COLD AIR ENTERS
HEAT SHROUD
EXHAUST MANIFOLD
AIR HEATED BY MANIFOLD
TAC REDUCES HC & CO

FIGURE 3-1

The Thermostatic Air Cleaner, also known as heated air control, provides for adjustment of intake air temperature going to the carburetor. Figure 3-1 shows the complete system, air cleaner, heat shroud and connecting hose. This system reduces hydrocarbons (HC) and carbon monoxide (CO).

Automotive manufacturers have found several other benefits by preheating the air before it enters the carburetor. This heated air allows for better atomization of fuel, better cold engine operation and elimination of carburetor icing, thus providing smoother engine operation.

The Thermostatic Air Cleaner is a key device in many auto emissions control systems. Two types are widely used: the thermostatic type as shown in Figure 3-2 and the air valve type as shown in Figure 3-3.

Regardless of the type of air cleaner, air valve or thermostatic, their job is the same - to provide for adjustments of intake air temperature.

Each type of thermostatic air cleaner has three modes, or positions of operation, which are: the cold air delivery mode, the regulating mode, and the hot air delivery mode.

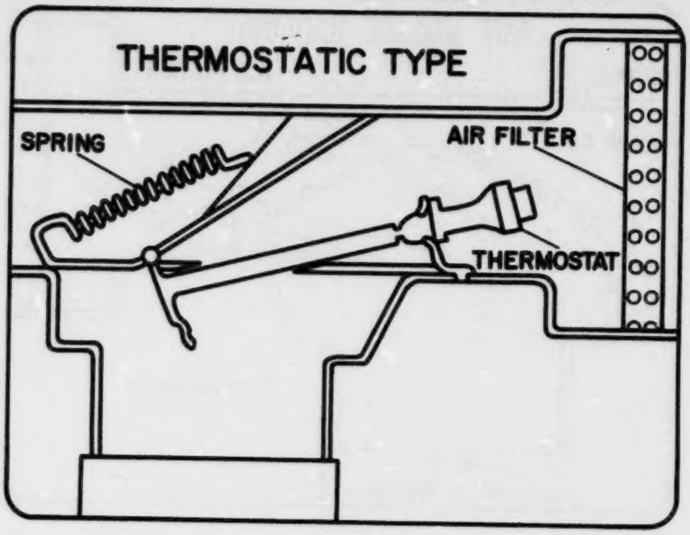

THERMOSTATIC TYPE
SPRING
AIR FILTER
THERMOSTAT

FIGURE 3-2

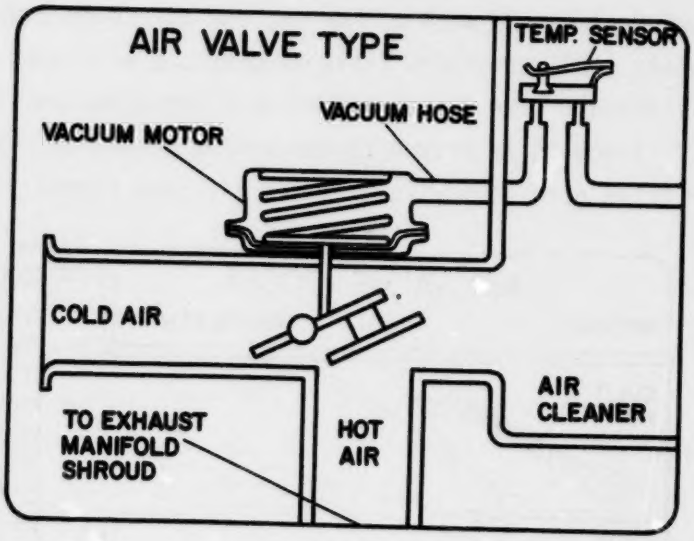

AIR VALVE TYPE
TEMP. SENSOR
VACUUM HOSE
VACUUM MOTOR
COLD AIR
AIR CLEANER
TO EXHAUST MANIFOLD SHROUD
HOT AIR

FIGURE 3-3

Figure 3-4 shows a cutaway of a Thermostatic Air Cleaner showing the air filter, thermostat, air valve door and snorkel. The snorkel admits engine compartment or fresh air to the air cleaner. This is referred to as cold air. It is the function of the thermostat acting on the air valve door which determines whether cold air or heated air from the shroud of the exhaust manifold is allowed to enter the carburetor.

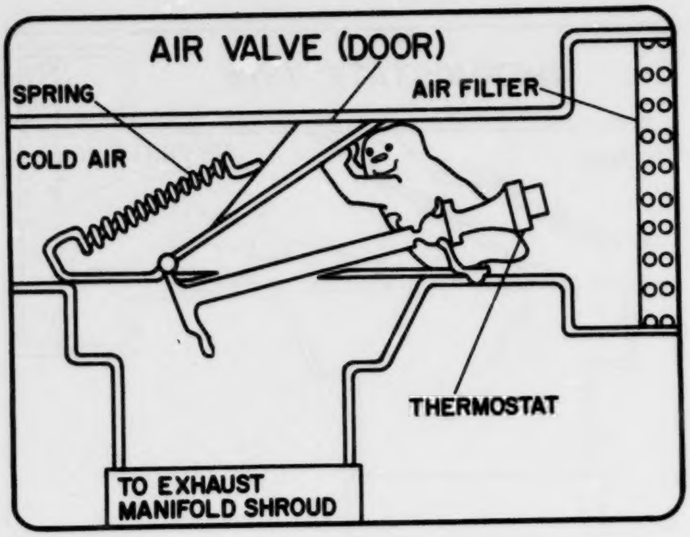

AIR VALVE (DOOR)
SPRING
AIR FILTER
COLD AIR
THERMOSTAT
TO EXHAUST MANIFOLD SHROUD

FIGURE 3-4

During engine start and warm-up period, the air temperature is below approximately 105°F or 40.5°C (this temperature will vary slightly for each application). The thermostat is in a retracted position, or "hot air mode." Since it is linked to the spring loaded air valve door, it holds the valve open to manifold heated air (see Figure 3-5).

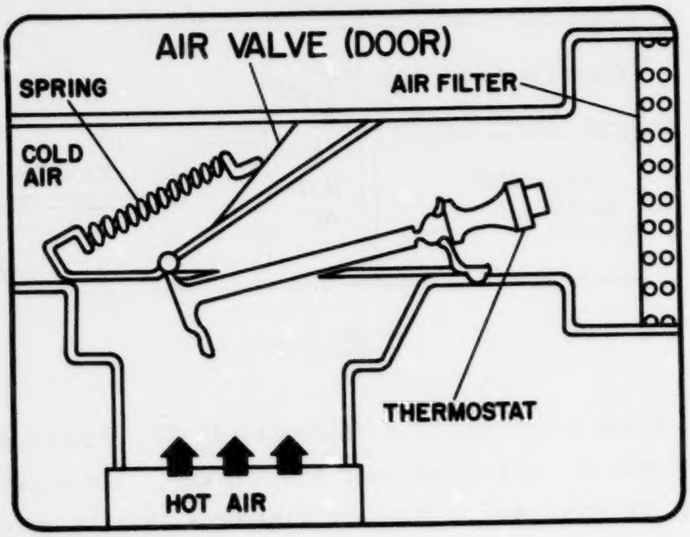

AIR VALVE (DOOR)
SPRING
AIR FILTER
COLD AIR
THERMOSTAT
HOT AIR

FIGURE 3-5

This shuts off the cold air and allows only air into the carburetor that is drawn from the heat shroud being heated by the exhaust manifold.

As the manifold heated air increases in temperature to approximately 105°F or 40.5°C, the thermostat begins to extend and pulls the air valve door downward allowing some cold air to enter the carburetor. It is then in the "regulating mode" as shown in Figure 3-6.

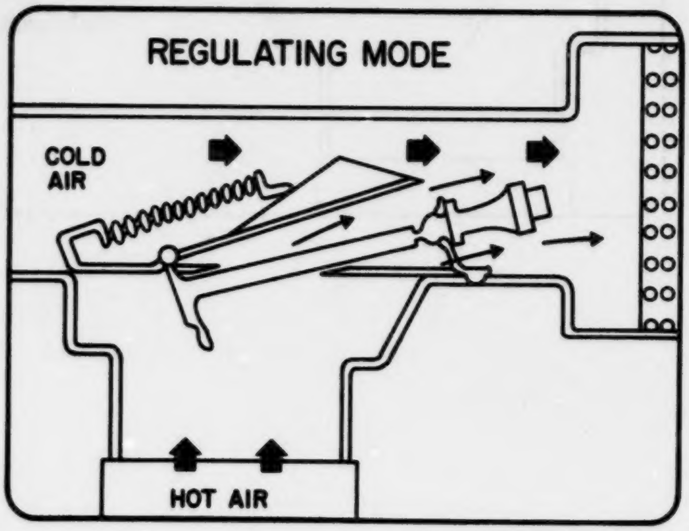


FIGURE 3-6

When the temperature reaches approximately 130°F or 54.4°C, the air valve door is fully opened to cold air and is in the "cold air mode," allowing only cold air from the snorkel to enter the carburetor. This condition is shown in Figure 3-7.

Remember - the purpose of temperature controlled air cleaners is to keep incoming air temperature at approximately 100°F or higher. This temperature enhances a more complete combustion which reduces HC and CO emissions.

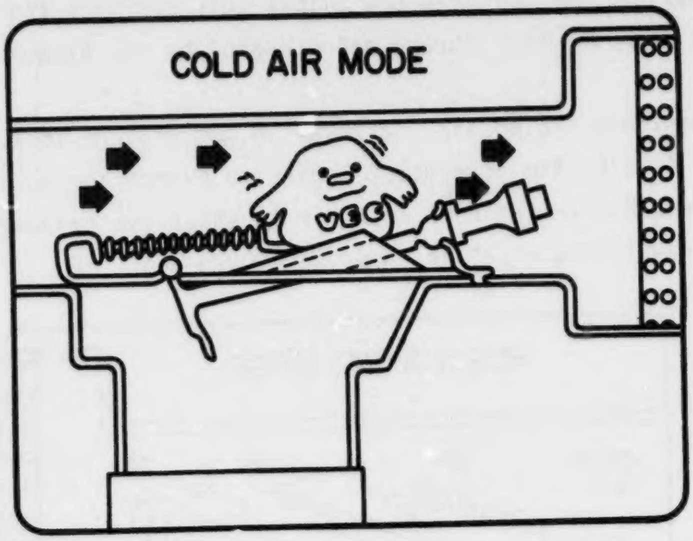

COLD AIR MODE
VEG

FIGURE 3-7

CHAPTER 4

AIR INJECTION REACTION

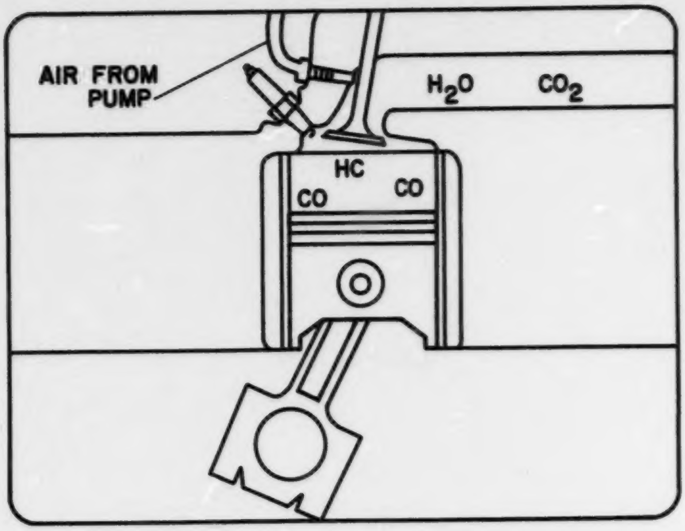


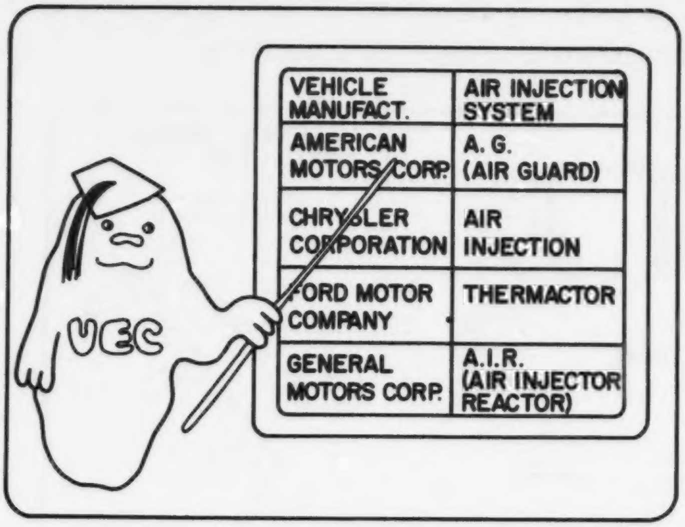
FIGURE 4-1

The purpose of the air injection system is to reduce carbon monoxide and hydrocarbon emissions by injecting a flow of air into the hot exhaust gases. The oxygen (O_2) in the air combines chemically with the carbon monoxide (CO) to form carbon dioxide (CO_2), a harmless gas. It also combines with the hydrocarbons (HC) to produce water (H_2O) and carbon dioxide (CO_2), usually in vapor form. This process is shown in Figure 4-1. Therefore, the air injection reaction system reduces both hydrocarbons and carbon monoxide.

Different manufacturers call the air injection system by different names but the function is the same. American Motors calls it "Air Guard." Chrysler calls it "Air Injection." Ford calls it "Thermactor." General Motors calls it "AIR" or "Air Injection Reactor" (Figure 4-2).

Figure 4-3 shows a typical "Air Injection" system and its components.

The air injection system uses an air pump as a source of air. It also has a diverter valve to prevent backfire in the exhaust system during deceleration. These parts are shown encircled in Figure 4-4. When the engine decelerates there is low pressure in the cylinder because the



VEHICLE MANUFACT.	AIR INJECTION SYSTEM
AMERICAN MOTORS CORP.	A. G. (AIR GUARD)
CHRYSLER CORPORATION	AIR INJECTION
FORD MOTOR COMPANY	THERMACTOR
GENERAL MOTORS CORP.	A.I.R. (AIR INJECTOR REACTOR)

FIGURE 4-2

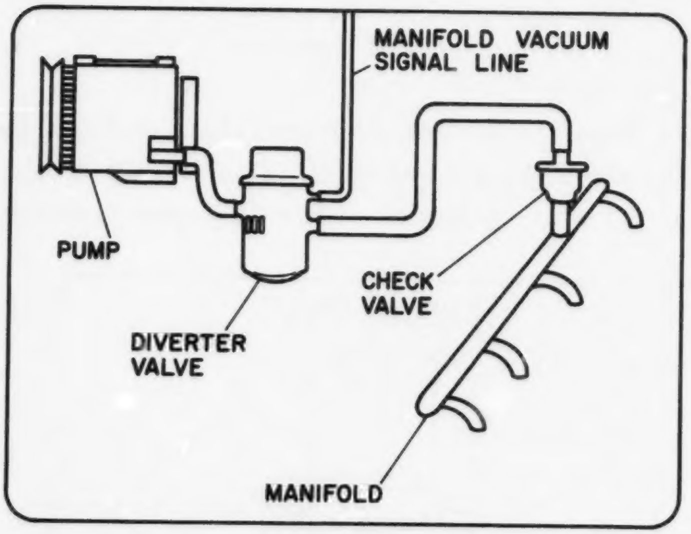

MANIFOLD VACUUM SIGNAL LINE
PUMP
CHECK VALVE
DIVERTER VALVE
MANIFOLD

FIGURE 4-3

throttle valve is closed, preventing air from filling the cylinder on the intake stroke. Under this condition the mixture is too rich to burn in the cylinder and a raw air/fuel mixture is pushed into the exhaust manifold. If the air injection system added air to this mixture, a burn should take place in the exhaust system causing a backfire. The diverter valve shuts air injection off during the initial 1 to 3 seconds of deceleration thereby preventing a backfire.

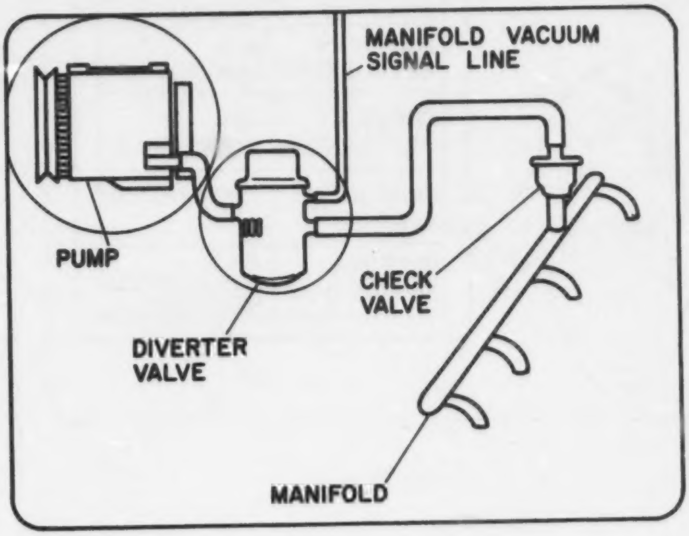

MANIFOLD VACUUM SIGNAL LINE
PUMP
CHECK VALVE
DIVERTER VALVE
MANIFOLD

FIGURE 4-4

After the air flows through the diverter valve, it flows through a hose or pipe to the check valve. The check valve (Figure 4-5) is open anytime the pressure in the air injection system is higher than the pressure in

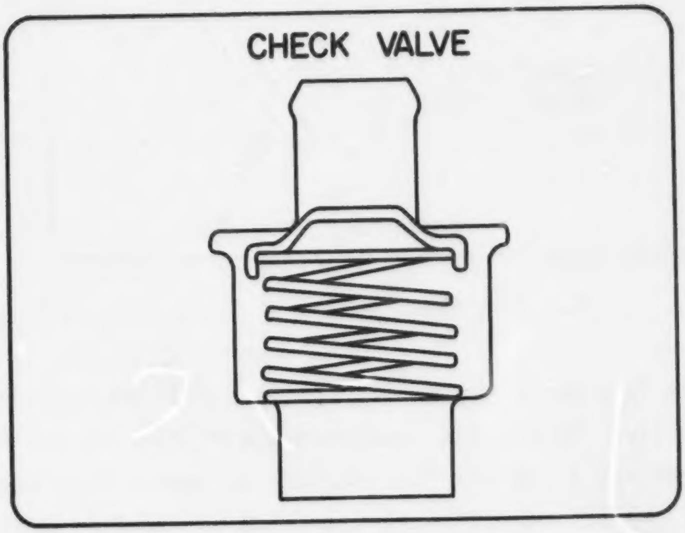

CHECK VALVE

FIGURE 4-5

the exhaust system. The check valve prevents the back flow of exhaust gas in the event of a pump failure or during times when exhaust pressure is higher than the air injection system pressure.

After the check valve, the air flows into the air injection manifold for distribution into each exhaust port near the exhaust valve. The pump, diverter valve, check valve, and injection manifold are connected with hoses and pipes to complete the system as shown in Figure 4-6.

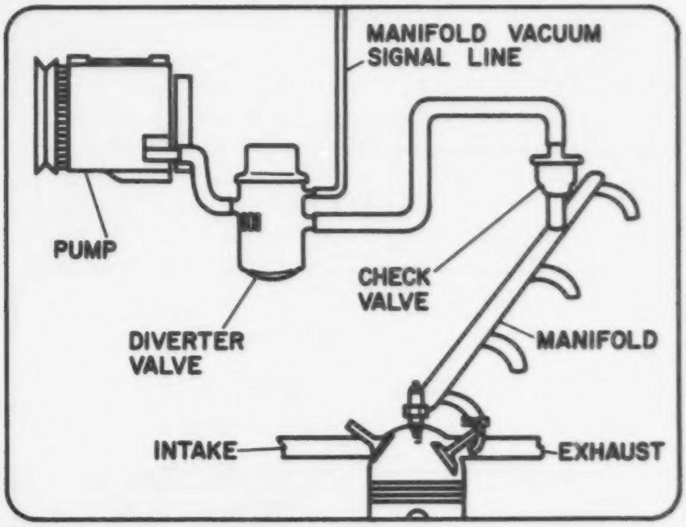


FIGURE 4-6

Figure 4-7 shows an air injection system connected to a V-8 engine. You will notice it has an air injection manifold for each bank of cylinders.

The air flow during operation is from the pump to the outlet hose, through the diverter or bypass valve and connecting hose to the check valve and into the air manifold for distribution to each exhaust valve port as illustrated in Figure 4-8.

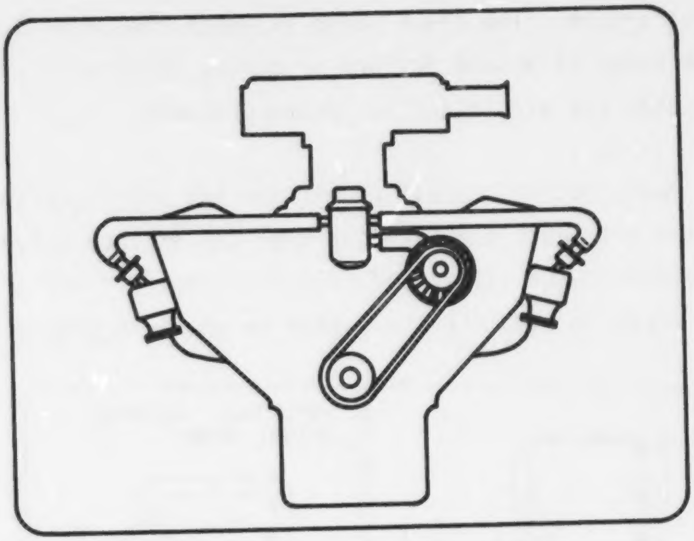


FIGURE 4-7

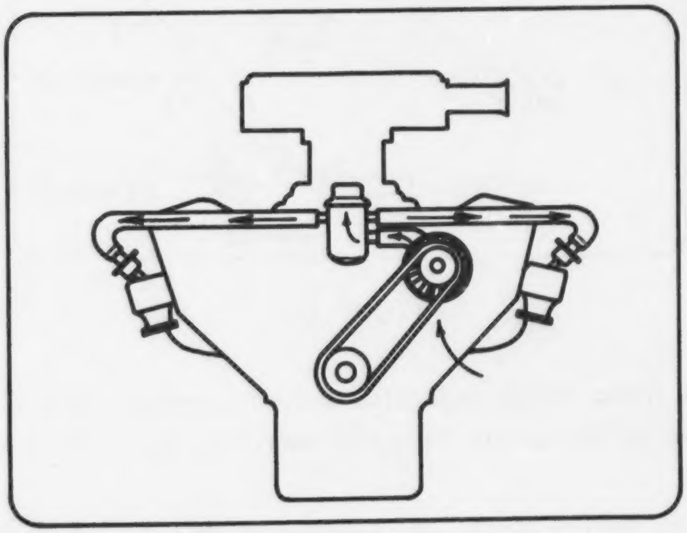


FIGURE 4-8

Figure 4-9 illustrates typically how the belt-driven air pump is mounted on the front of the engine.

Figure 4-10 is a simplified view of the inside of the air pump. The arrows show the movement of air by the vanes through the pump. The number of vanes varies from 2 to 5.

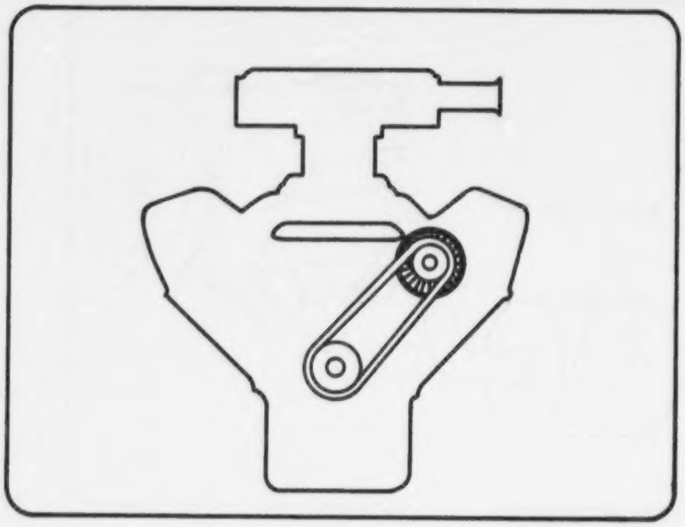


FIGURE 4-9

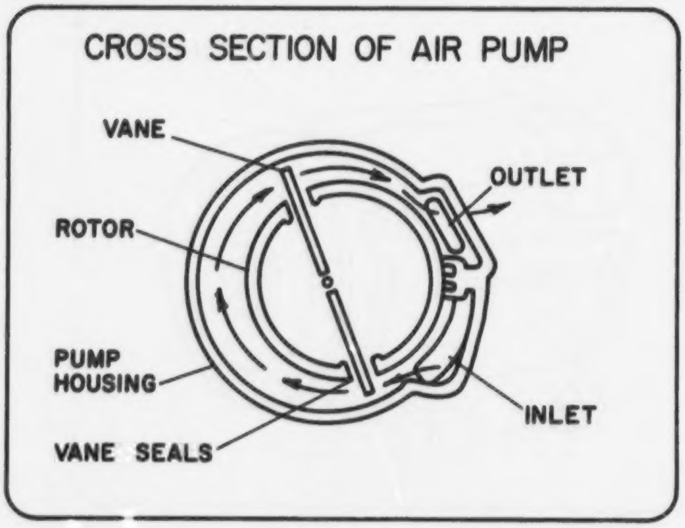

CROSS SECTION OF AIR PUMP
VANE
OUTLET
ROTOR
PUMP HOUSING
INLET
VANE SEALS

FIGURE 4-10

Air enters the air pump in either of two ways. One is by an external air filter such as shown in Figure 4-11 or through a centrifugal fan filter shown in Figure 4-12. The centrifugal filter is by far the most popular.

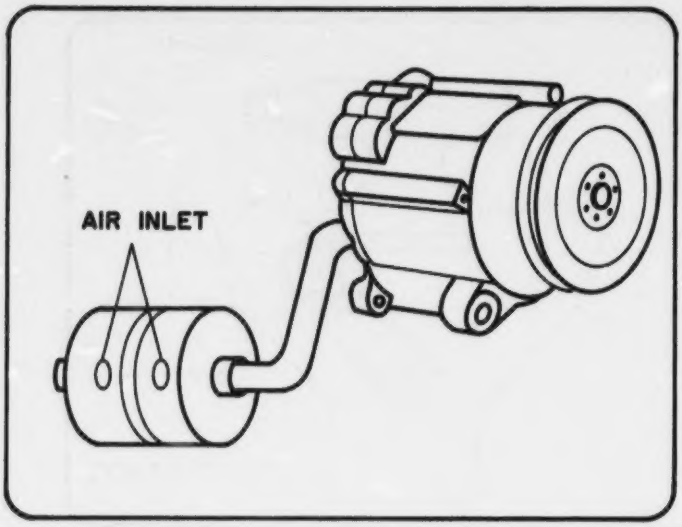


FIGURE 4-11

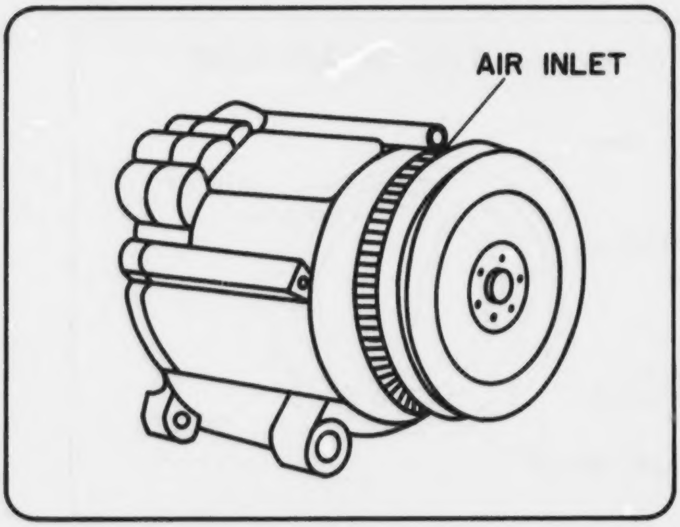


FIGURE 4-12

Output air from the pump (Figure 4-13) leaves the discharge connection of the pump and flows into the connecting hose leading to the diverter valve.

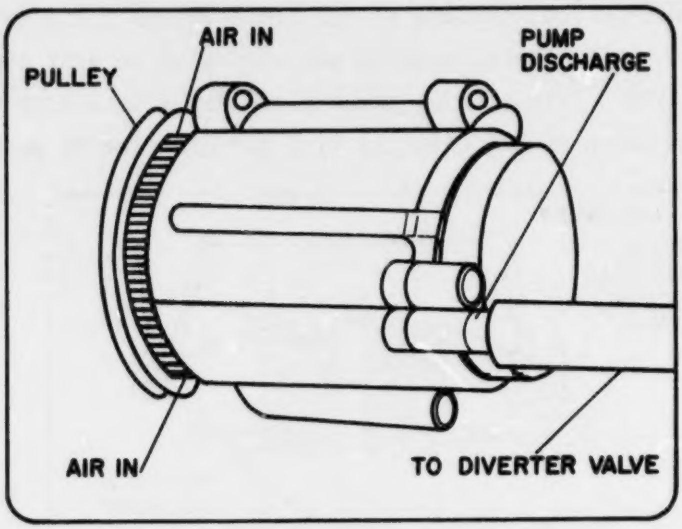

AIR IN
PULLEY
PUMP
DISCHARGE
AIR IN
TO DIVERTER VALVE

FIGURE 4-13

Two types of valves are used to prevent backfire. These types are shown in Figure 4-14. One type, the gulp valve, allows pump air to be sent to the intake manifold on deceleration to dilute the rich mixture preventing backfire. The diverter valve prevents air from entering the air injection manifold by venting pump air to the atmosphere during deceleration.

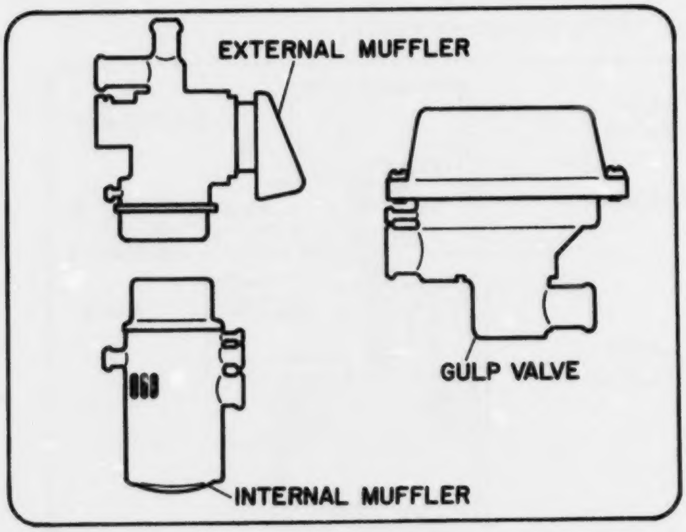

EXTERNAL MUFFLER
GULP VALVE
INTERNAL MUFFLER

FIGURE 4-14

The gulp valve operates when intake manifold vacuum reaches about 20-22 inches of mercury (Hg) (Figure 4-15). This vacuum pulls the diaphragm down against spring force, opening the air valve to vent pump air to the intake manifold. This venting takes place for 1 to 3 seconds of initial deceleration which is the critical time for backfire to occur.

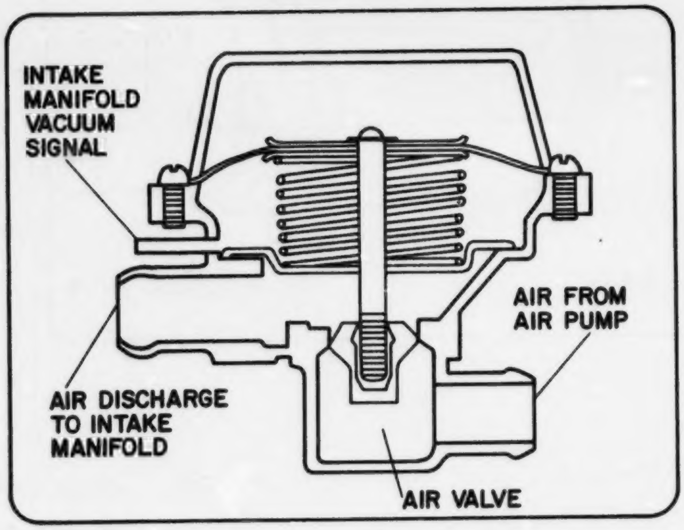

INTAKE MANIFOLD VACUUM SIGNAL
AIR FROM AIR PUMP
AIR DISCHARGE TO INTAKE MANIFOLD
AIR VALVE

FIGURE 4-15

Figure 4-16 shows a cutaway view of the combination diverter pressure regulator valve. Parts shown are the diaphragm and spring, stem, valve plates and manifold vacuum entrance.

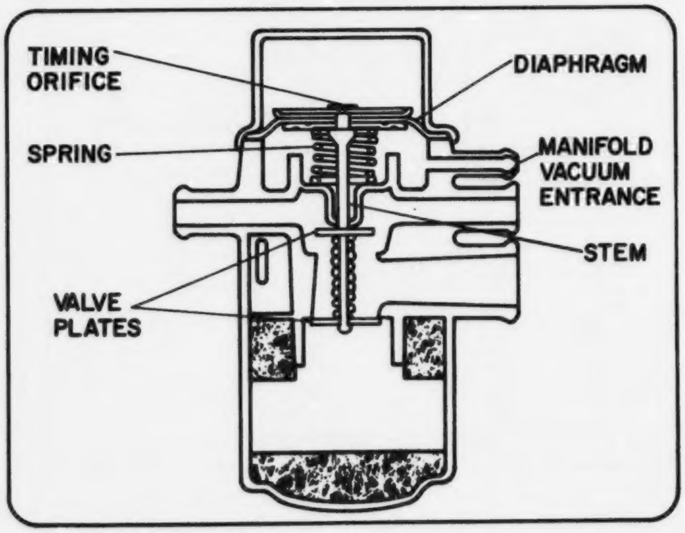

TIMING ORIFICE
DIAPHRAGM
SPRING
MANIFOLD VACUUM ENTRANCE
STEM
VALVE PLATES

FIGURE 4-16

When the engine is operating, vacuum is applied to both sides of the diaphragm equally by means of a timing orifice in the diaphragm. The diaphragm spring raises the stem and unseats the upper valve plate as shown in Figure 4-17.

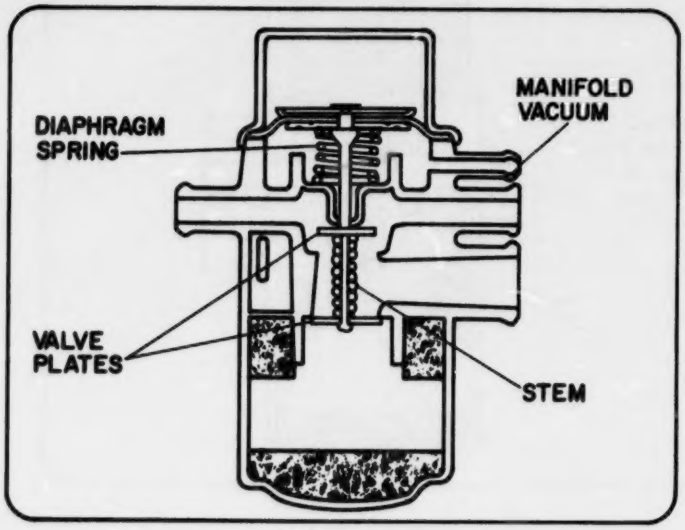

MANIFOLD VACUUM
DIAPHRAGM SPRING
VALVE PLATES
STEM

FIGURE 4-17

The air flow under this condition flows in from the pump through the diverter valve and into the exhaust manifold or manifolds (Figure 4-18).

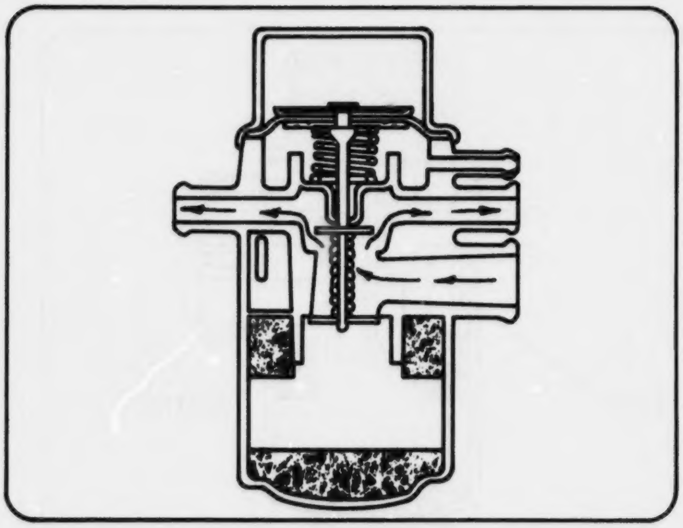


FIGURE 4-18

During periods of deceleration, higher manifold vacuum is imposed on the lower side of the diaphragm than on the upper side. The diaphragm forces the stem and valves to be moved downward against spring force (Figure 4-19).

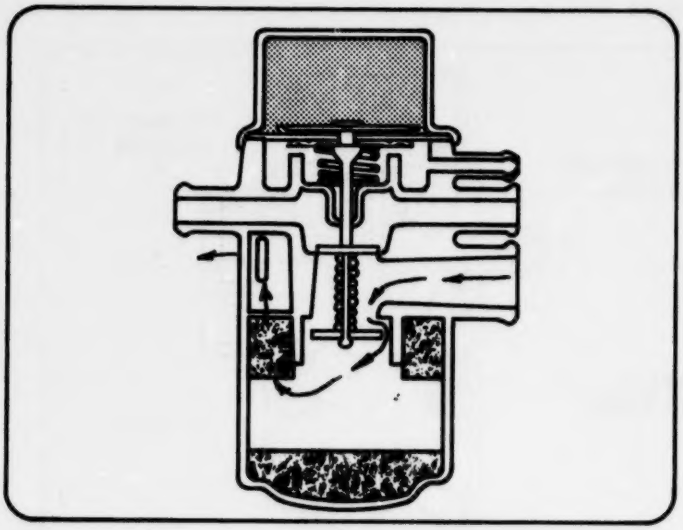


FIGURE 4-19

When the stem moves down, the upper valve plate seats and the lower valve plate opens allowing the pump air to vent to atmosphere until the vacuum on the diaphragm becomes equal on both sides by flow through the diaphragm timing orifice as illustrated in Figure 4-20.

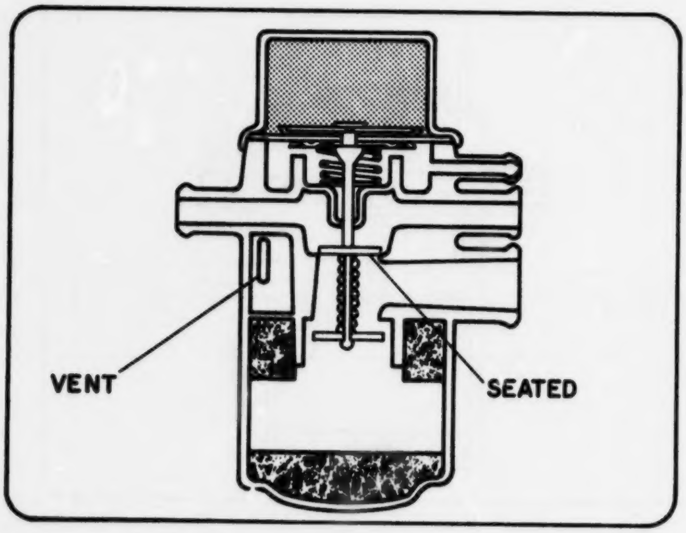


FIGURE 4-20

When the engine is turning at a high RPM, excessive pressure is produced. In the combination diverter and pressure regulator valve, the lower valve plate is forced down and excessive air flow is allowed to vent to the atmosphere (Figure 4-21).

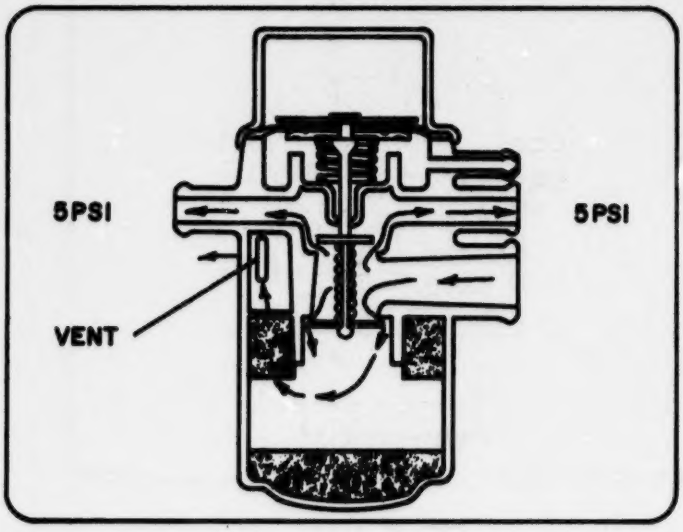

5PSI
5PSI
VENT

FIGURE 4-21

Illustration 4-22 shows the relationship of the check valve and air injection manifold.

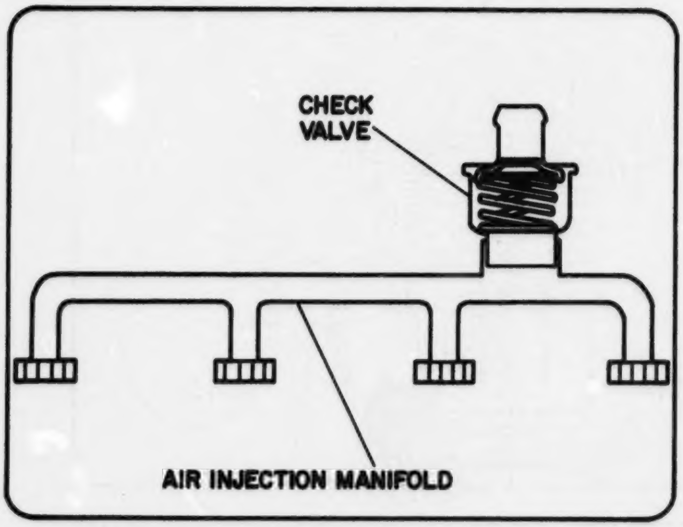

CHECK VALVE
AIR INJECTION MANIFOLD

FIGURE 4-22

Figure 4-23 shows a cutaway view of the check valve and air flow when the system has higher pressure than the exhaust system.

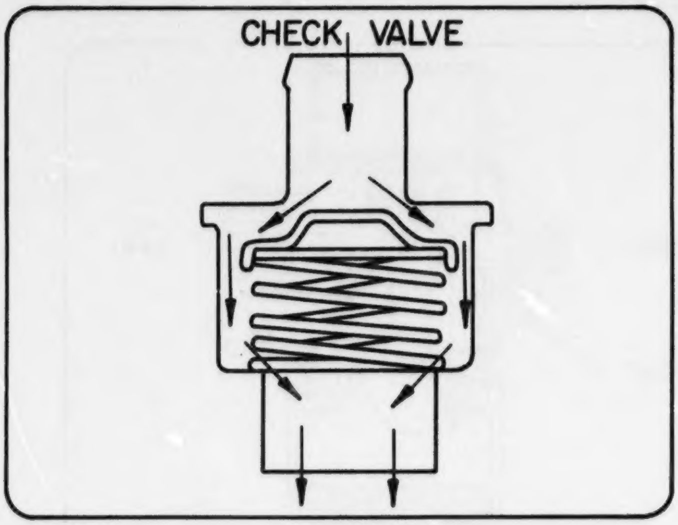


FIGURE 4-23

Figure 4-24 shows the check valve seated during the time when the exhaust back pressure is higher than the air pressure from the pump.

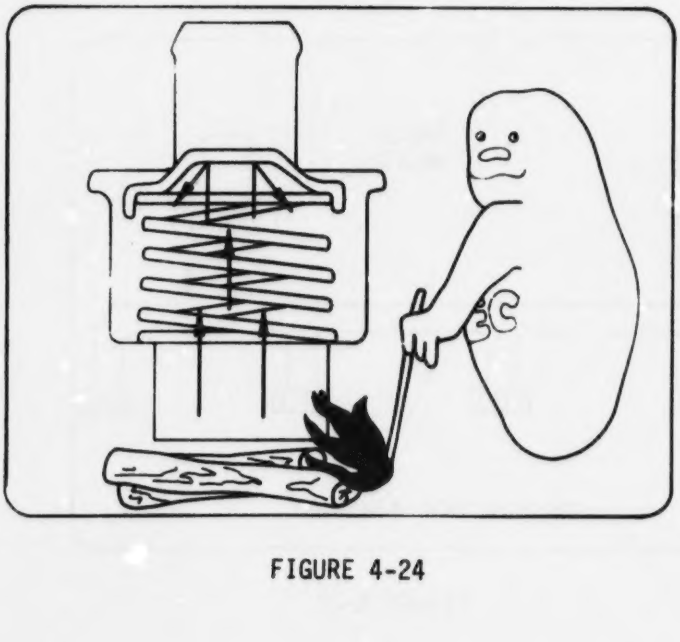


FIGURE 4-24

Illustrated in Figure 4-25 are the air manifolds and tubes as used on a typical 6 and 8 cylinder engine. Usually one tube is used for each exhaust port. On some vehicles the manufacturers have omitted one distribution tube, usually because of design problems.

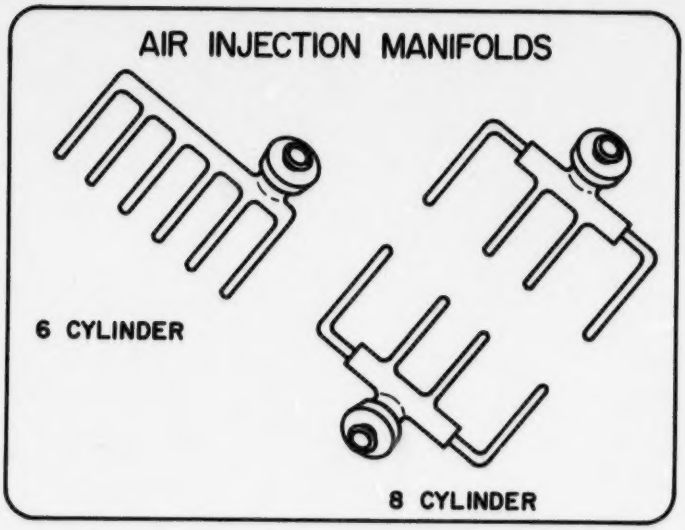


FIGURE 4-25

Remember - The AIR system reduces HC and CO by injecting air into the exhaust manifold. This added air speeds up the oxidation process of HC and CO and results in lower emissions.

CHAPTER 5

FUEL EVAPORATIVE CONTROL

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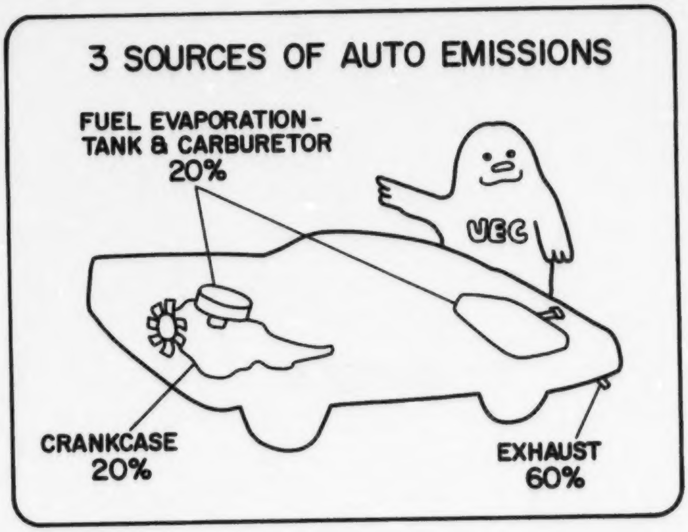
3 SOURCES OF AUTO EMISSIONS
FUEL EVAPORATION - TANK & CARBURETOR 20%
UEC
CRANKCASE 20%
EXHAUST 60%

FIGURE 5-1

It is estimated that on the pre-emissions controlled automobile about 20% of all emissions consist of gasoline hydrocarbon vapors that evaporate from the carburetor and fuel tank.

To eliminate these evaporative losses, automobile manufacturers developed control systems beginning in 1970 for cars in California. Nationally in 1971, all U.S. automobile manufacturers equipped their vehicles with the following evaporative control devices:

1) A fuel tank safety filler cap which seals the system.
2) A special fuel tank designed to allow space for fuel expansion.
3) A venting system to carry vapors from the fuel tank to the engine for eventual burning.

A venting system includes a liquid check valve or a liquid vapor separator to keep liquid fuel out of the vent lines, a charcoal canister to store the vapors and connecting lines to carry the vapor from the canister to the engine for burning (Figure 5-2). Chrysler used a crankcase storage system for the first two years instead of the canister, but its function was the same.

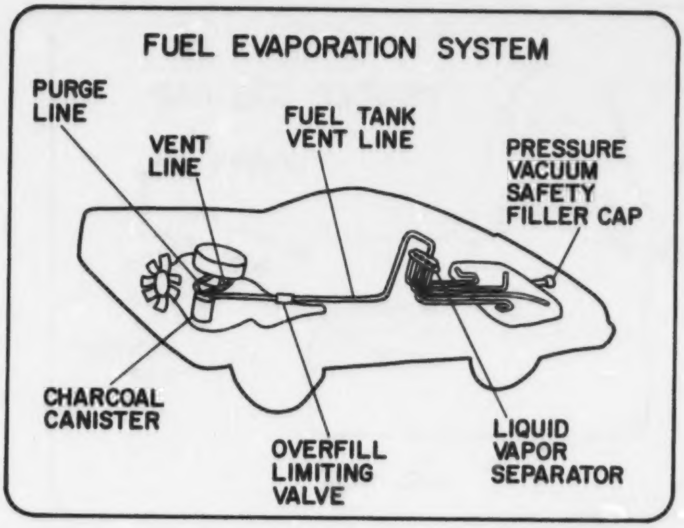
FUEL EVAPORATION SYSTEM
PURGE LINE
VENT LINE
FUEL TANK VENT LINE
PRESSURE VACUUM SAFETY FILLER CAP
CHARCOAL CANISTER
OVERFILL LIMITING VALVE
LIQUID VAPOR SEPARATOR

FIGURE 5-2

The fuel evaporative emissions control systems used by most U.S. automobile manufacturers are similar, sometimes almost identical. However, there are some minor differences, mainly in the name. Following is a list of names given the fuel evaporative systems by different manufacturers:

American Motors	Fuel Tank Vapor Control
Chrysler	Vapor Saver
Ford	Evaporation Control System
General Motors	Evaporative Emissions Control
Foreign	Fuel Vapor Recovery System

Before emissions control, fuel caps and fuel tanks were vented to allow raw fuel vapors or even liquid gasoline to escape, unrestricted, into the atmosphere. An illustration of this system is shown in Figure 5-3.

In the present fuel tank filler cap, a safety pressure relief valve will open only if pressure from one-half to one psi builds in the tank (Figure 5-4).

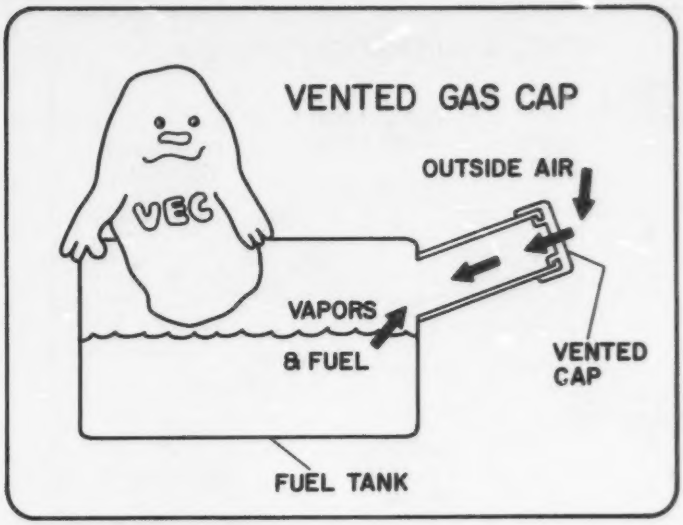
VENTED GAS CAP
VEC
OUTSIDE AIR
VAPORS
& FUEL
VENTED CAP
FUEL TANK

FIGURE 5-3

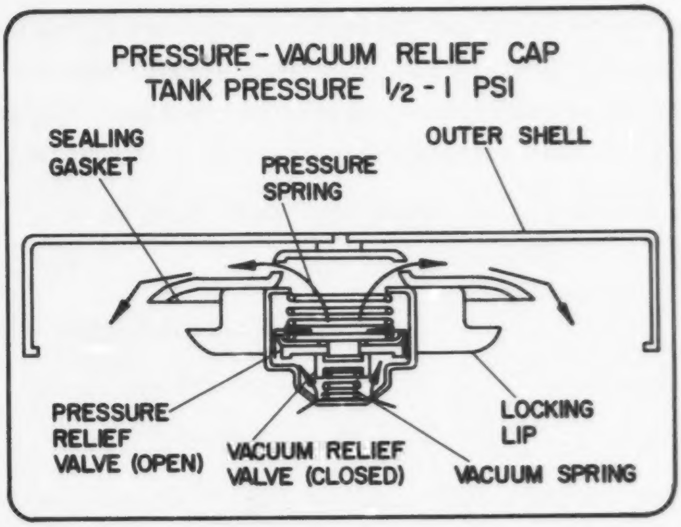
PRESSURE-VACUUM RELIEF CAP
TANK PRESSURE 1/2 - 1 PSI
SEALING GASKET
PRESSURE SPRING
OUTER SHELL
PRESSURE RELIEF VALVE (OPEN)
VACUUM RELIEF VALVE (CLOSED)
LOCKING LIP
VACUUM SPRING

FIGURE 5-4

If a vacuum of one-fourth to one-half inch mercury (Hg) buildup occurs, the safety vacuum relief valve will open to let in some outside air, but normally the cap is sealed (Figure 5-5).

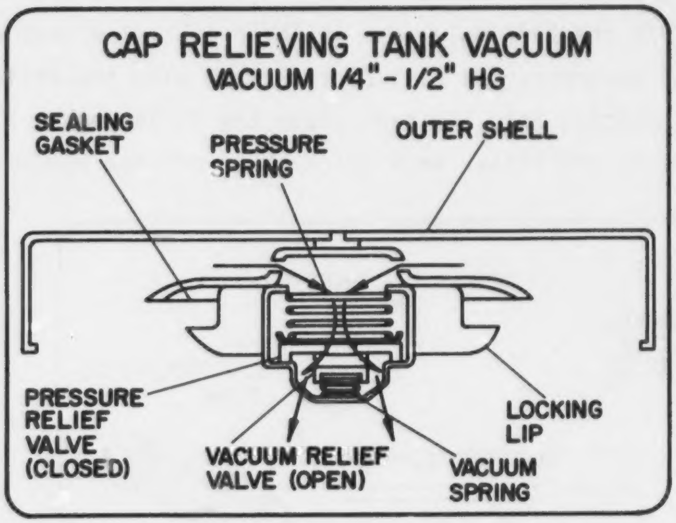
CAP RELIEVING TANK VACUUM
VACUUM 1/4"-1/2" HG
SEALING GASKET
PRESSURE SPRING
OUTER SHELL
PRESSURE RELIEF VALVE (CLOSED)
VACUUM RELIEF VALVE (OPEN)
VACUUM SPRING
LOCKING LIP

FIGURE 5-5

The filler neck on most fuel tanks extends below the top of the tank preventing the tank from being filled 100%. This provides an expansion space of 10 to 12% of tank capacity at the top to allow room for the gasoline to expand when the temperatures increase (See Figure 5-6).

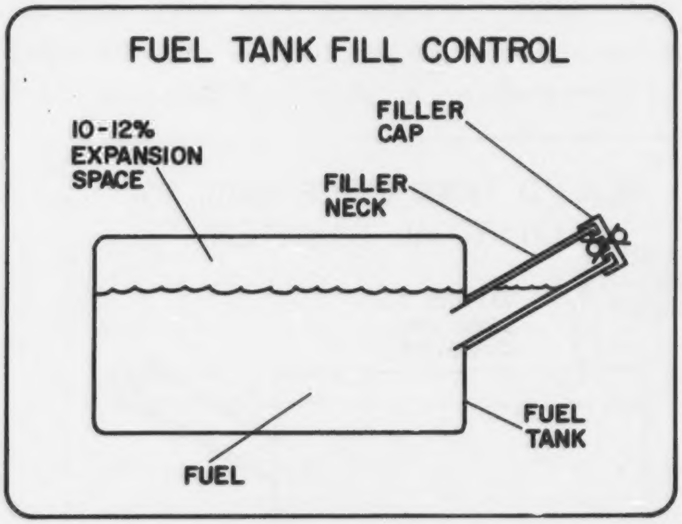
FUEL TANK FILL CONTROL
10-12% EXPANSION SPACE
FILLER CAP
FILLER NECK
FUEL TANK
FUEL

FIGURE 5-6

Some models, 1970 and 1971 only, use an inner expansion tank as shown in Figure 5-7, and incorporate a fill control tube with the filler neck. If fuel continues pumping into the tank above the filler neck, a fill control tube returns it to the filler neck which shuts off the automatic fill nozzle.

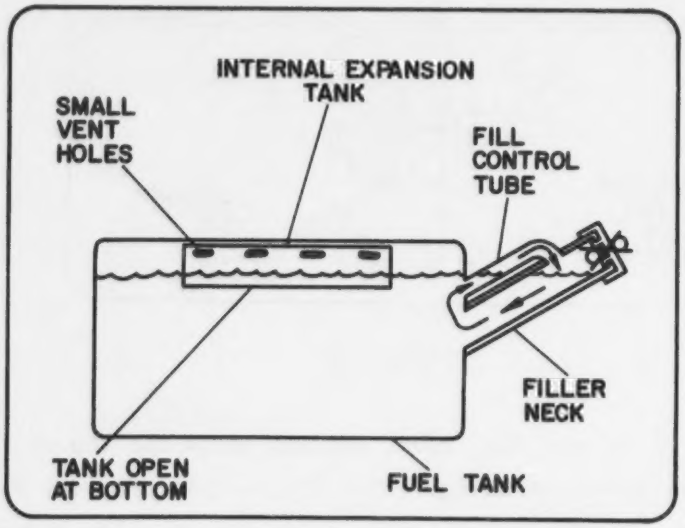
INTERNAL EXPANSION TANK
SMALL VENT HOLES
FILL CONTROL TUBE
FILLER NECK
TANK OPEN AT BOTTOM
FUEL TANK

FIGURE 5-7

With the fuel tank sealed to atmosphere, fuel vapors will collect at the top of the tank and have only one way to go -- into the venting lines to be stored in the storage device as shown in Figure 5-8.

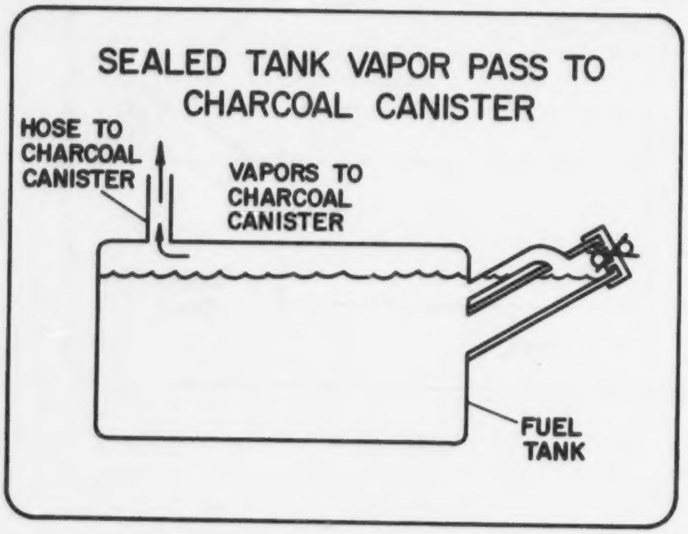
SEALED TANK VAPOR PASS TO CHARCOAL CANISTER
HOSE TO CHARCOAL CANISTER
VAPORS TO CHARCOAL CANISTER
FUEL TANK

FIGURE 5-8

In tanks without internal or separate expansion tanks, an internal expansion space must be provided into which fuel or fuel vapor can safely expand, as illustrated in Figure 5-9. This volume is approximately ten to twelve percent of the fuel tank volume.

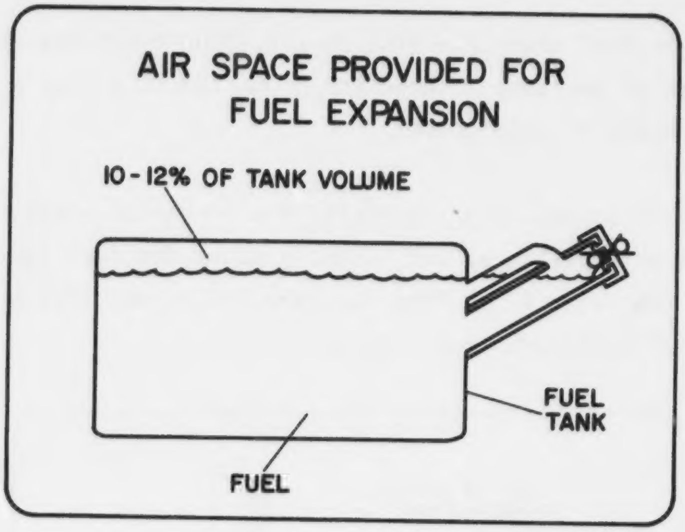
AIR SPACE PROVIDED FOR FUEL EXPANSION
10-12% OF TANK VOLUME
FUEL TANK
FUEL

FIGURE 5-9

Some manufacturers, such as Volkswagen, use an external expansion chamber. In operation, liquid fuel rising from the tank is routed to the expansion chamber (Figure 5-10). The chamber is designed to permit the passage of

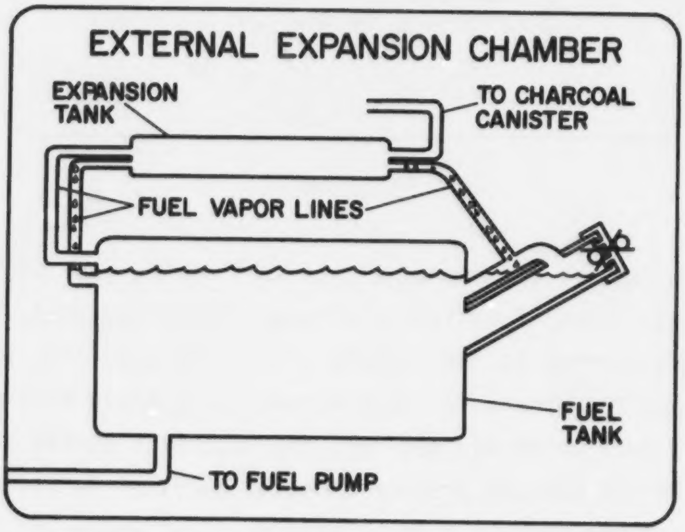
EXTERNAL EXPANSION CHAMBER
EXPANSION TANK
TO CHARCOAL CANISTER
FUEL VAPOR LINES
FUEL TANK
TO FUEL PUMP

FIGURE 5-10

fuel vapors, but to prevent the passage of liquid fuel. From this external chamber, the fuel vapors are carried forward into a container filled with activated charcoal where they are stored when the engine is not running. The liquid is drained back to the tank.

Because some fuel tanks are flat on top, four vents are used, one in each corner of the tank. These are connected to a liquid vapor separator by rubber hoses or metal pipes.

The liquid vapor separator consists of a length of steel tubing which is mounted at an angle ahead and slightly above the fuel tank. This tubing holds the four vent lines from the tank and a vent line which leads to the charcoal canister. See Figure 5-11.

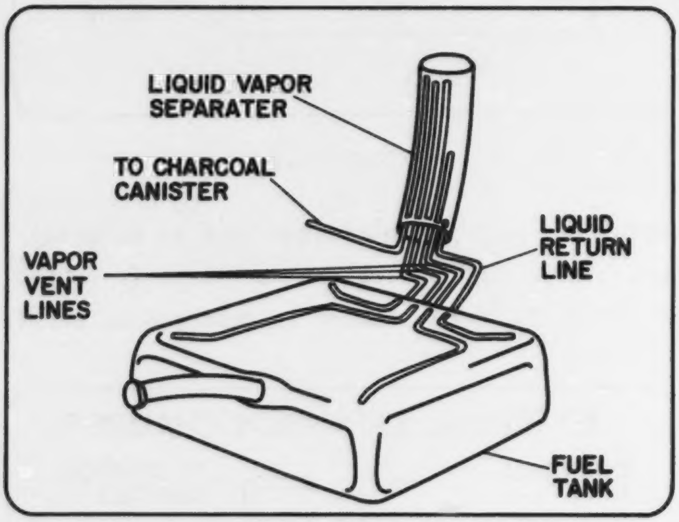

FIGURE 5-11

These lines are of different heights so that the tank will always be vented, regardless of vehicle altitude. This way, only the fuel vapors will be transferred to the storage area. One vent line from the tank is shorter than the others in order to provide a drain back to the tank for any liquid fuel which may get into the separator during inclined parking. The vent to the storage area or charcoal canister is at the highest point in the separator and has a small orifice to minimize liquid fuel transfer to the storage area or canister.

The next component of the evaporative systems is the Vapor Storage Canister which uses activated charcoal granules to store the vapors until they are drawn into the carburetor. The typical canister contains about one to one and one-half pounds of charcoal which provides an exposed surface area of about one-quarter square mile, enough to store almost a cup of liquid fuel when vaporized. This storage canister has two connections, the vent line from the fuel tank and a connecting vent line to the carburetor or air cleaner. An illustration of a charcoal canister is shown in Figure 5-12.

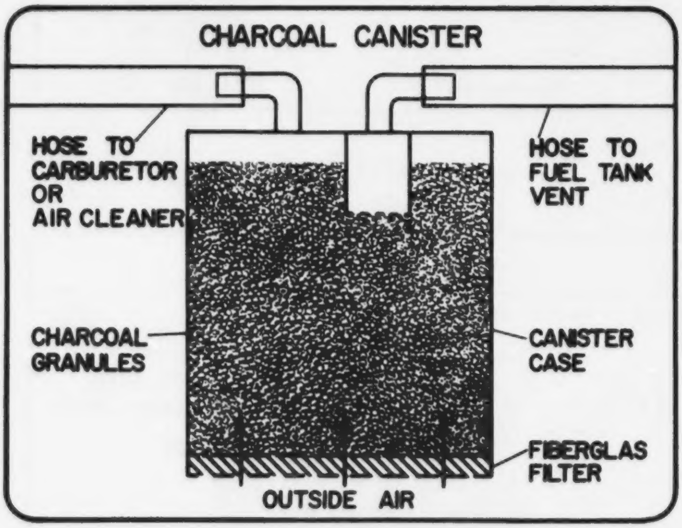
CHARCOAL CANISTER
HOSE TO CARBURETOR OR AIR CLEANER
HOSE TO FUEL TANK VENT
CHARCOAL GRANULES
CANISTER CASE
FIBERGLAS FILTER
OUTSIDE AIR

FIGURE 5-12

With the engine running, outside air is drawn through the canister to remove fuel vapors collected by the charcoal granules. This is called evacuation or purge cycle and is illustrated in Figure 5-13.

When the engine is running, and during the purge cycle (Figure 5-14), outside air is drawn through the fiberglass filter of the canister, through the carbon granules, picking up fuel vapors and carrying them to the air cleaner to become a part of the air/fuel mixture to be burned.

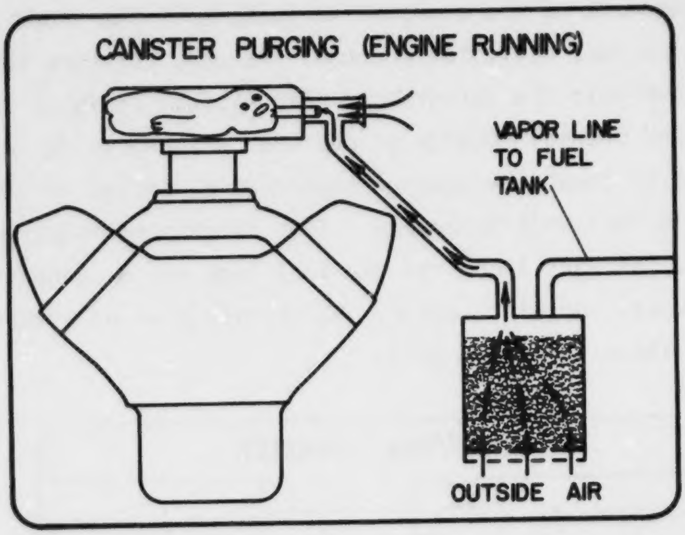
CANISTER PURGING (ENGINE RUNNING)
VAPOR LINE TO FUEL TANK
OUTSIDE AIR

FIGURE 5-13

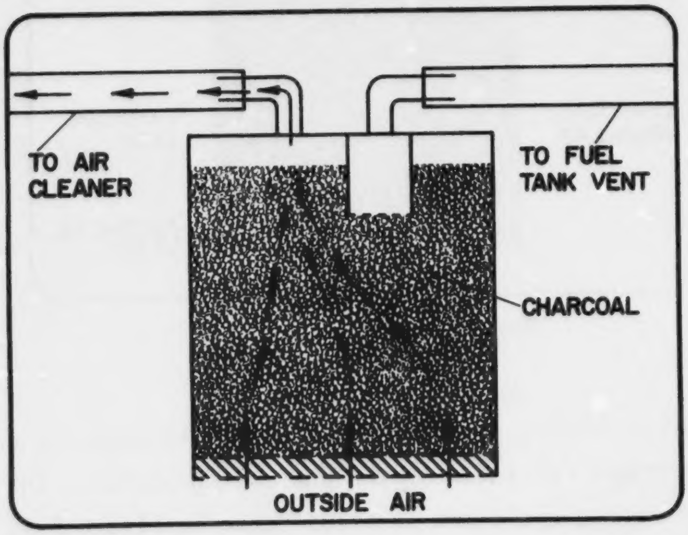
TO AIR CLEANER
TO FUEL TANK VENT
CHARCOAL
OUTSIDE AIR

FIGURE 5-14

Figure 5-15 shows a cross section of a stamped metal canister with an open space provided above and below the granules.

A center tube is incorporated which extends to the bottom of the canister. Air can enter at the top of the tube passing downward to the bottom of the canister. The canister purge line is externally attached (by hoses)

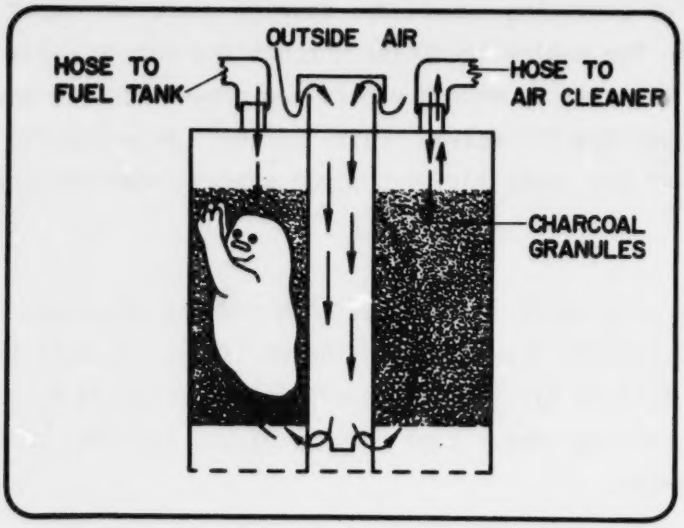
OUTSIDE AIR
HOSE TO FUEL TANK
HOSE TO AIR CLEANER
CHARCOAL GRANULES

FIGURE 5-15

to the carburetor air cleaner or the the PCV valve (depending on model application).

The vapor is purged out of the canister through the air outlet hose to the air cleaner (or PCV valve), then through the carburetor and into the combustion chamber -- where the vapors are consumed in the normal combustion process (Figure 5-16).

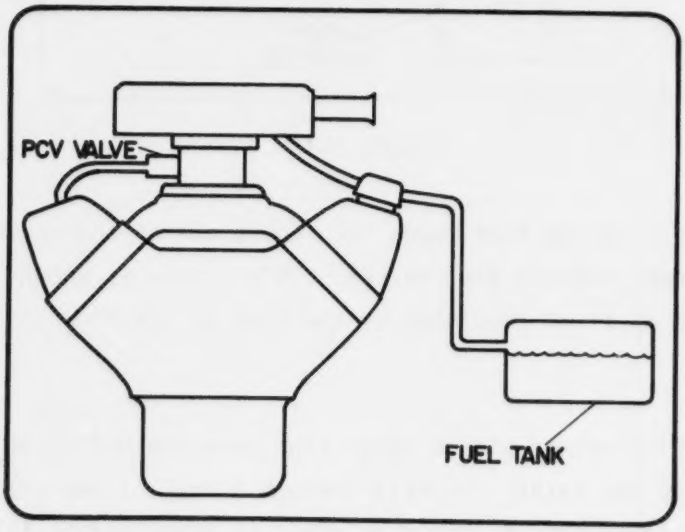
PCV VALVE
FUEL TANK

FIGURE 5-16

One method of providing additional storage space for vapor is to vent the fuel tank to the engine crankcase through the engine valve cover. When the engine is started, stored vapors are drawn into the engine intake system through the PCV valve. This "purges" the crankcase of stored vapor so they are ready for more vapor storage when the engine is turned off.

Vapor which originated in the fuel tank and was separated by the vapor liquid separator is now stored in the canister. In this system, (Figure 5-17), movement of air through the canister is caused by carburetor intake air passing over a tube which projects into the carburetor air cleaner snorkel.

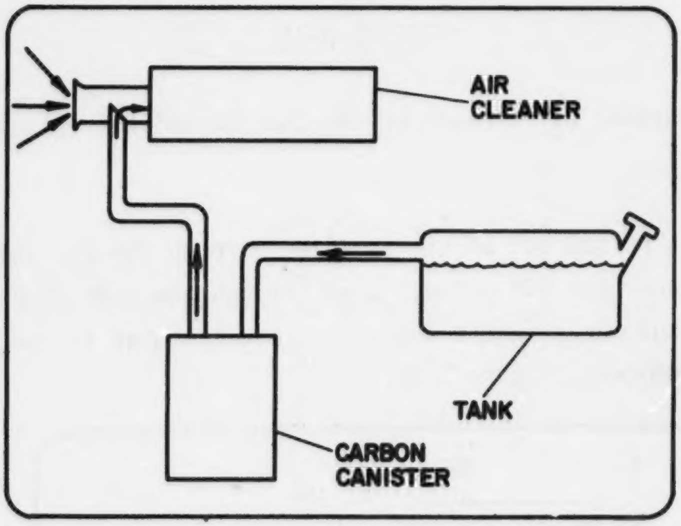

FIGURE 5-17

This creates a vacuum that moves the vapors out of the canister and into the air stream entering the snorkel. This system is known as a Variable Purge System as it is regulated by the rate of air flow entering the air cleaner.

Another purging method ties a purge line into the PCV valve line. Purging air passes to the intake manifold through a small fixed orifice on the canister outlet. This is known as constant purge and is illustrated in Figure 5-18.

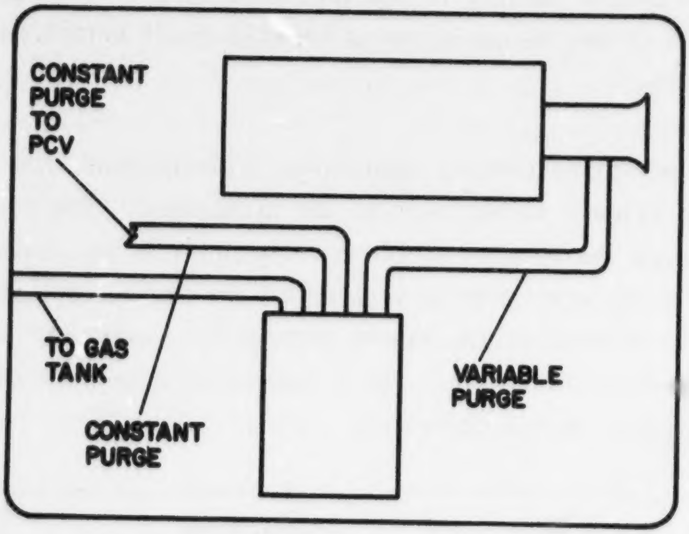
CONSTANT
PURGE
TO
PCV
TO GAS
TANK
CONSTANT
PURGE
VARIABLE
PURGE

FIGURE 5-18

Still another method used by some manufacturers is called the constant and demand purge system (Figure 5-19). A purge valve at the canister allows constant purging at a restricted rate through an orifice until a certain level of vacuum occurs at the canister outlet. When ported vacuum is applied to the purge valve, it allows a higher rate of purging to take place through the hose to intake manifold resulting in demand

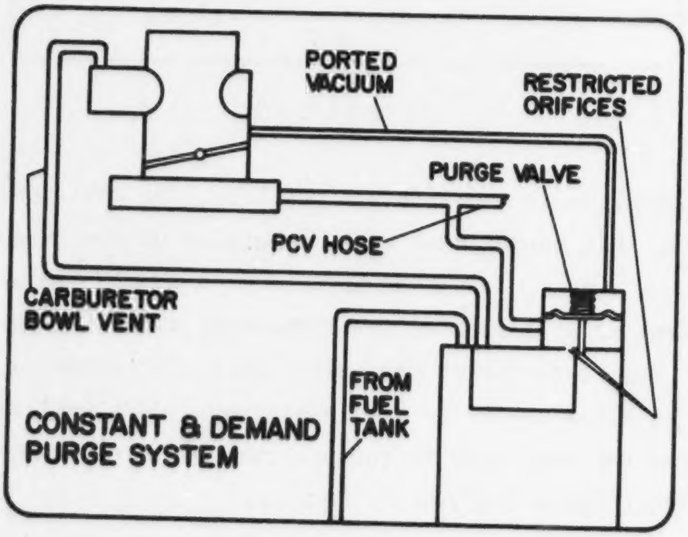
PORTED
VACUUM
RESTRICTED
ORIFICES
PURGE VALVE
PCV HOSE
CARBURETOR
BOWL VENT
FROM
FUEL
TANK
CONSTANT & DEMAND
PURGE SYSTEM

FIGURE 5-19

purging. Demand purging is designed to ensure that purging occurs during conditions of engine operation which will least affect performance and driveability.

Prior to emissions control regulation, hydrocarbons from the carburetor bowl were allowed to escape into the atmosphere. The advent of controls necessitated the venting of the carburetor into the canister and the removal of the atmosphereic venting of the carburetor. Figure 5-20 shows one method of controlling vapors through the carburetor external vent of an anti-perculation valve. The illustration shows the capped vent open to allow vapor to the canister.

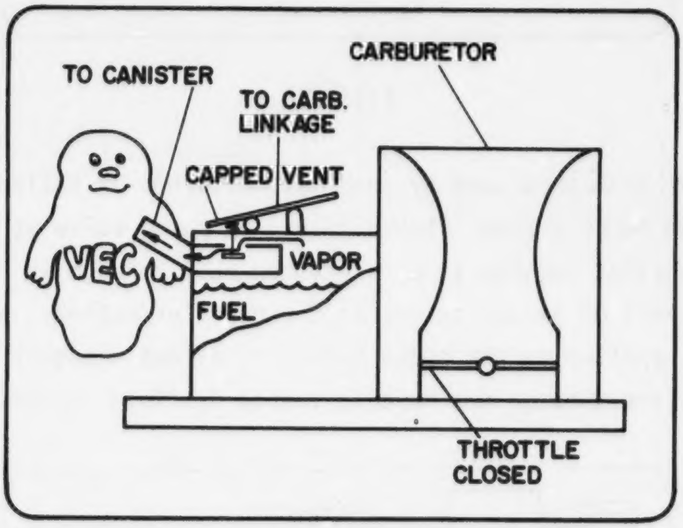

FIGURE 5-20

With the throttle in the off-idle position, the anti-perculator valve is closed. In this operational mode, no escape of fuel vapor occurs.

As a review, we will look at the components of the evaporative system again: a fuel tank filler cap which seals the system, a special fuel tank designed to allow space for fuel expansion, and a venting system to carry vapors from the fuel tank to the charcoal canister and into the engine for burning (Figure 5-21).

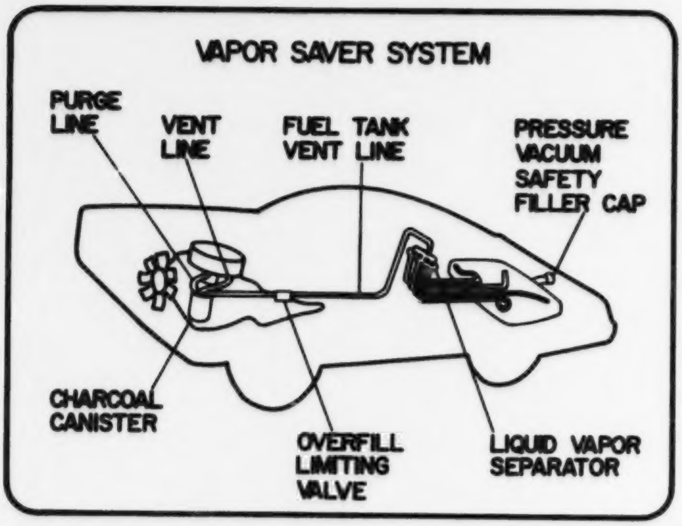
VAPOR SAVER SYSTEM
PURGE LINE
VENT LINE
FUEL TANK VENT LINE
PRESSURE VACUUM SAFETY FILLER CAP
CHARCOAL CANISTER
OVERFILL LIMITING VALVE
LIQUID VAPOR SEPARATOR

FIGURE 5-21

CHAPTER 6

EXHAUST GAS RECIRCULATION

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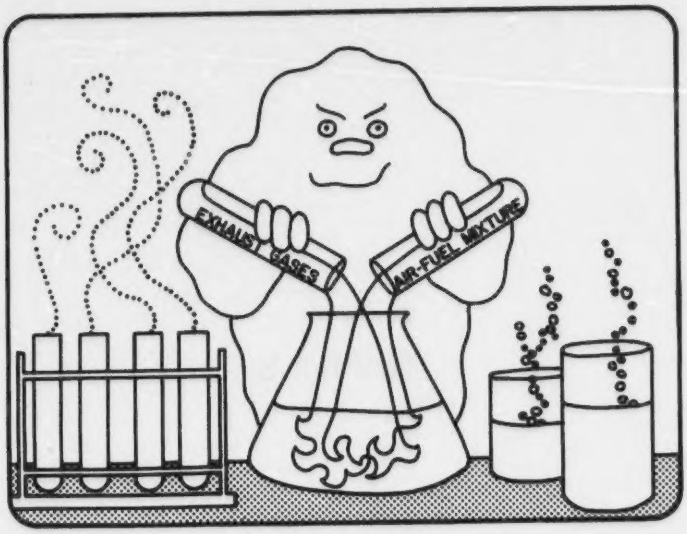

FIGURE 6-1

EGR or the Exhaust Gas Recirculation system reduces oxides of nitrogen emissions by recirculating regulated amounts of exhaust gases with the air/fuel mixture before entering the combustion chamber. As VEC is showing us in Fiugre 6-1, the air/fuel mixture is diluted with exhaust gases which reduce the combustion temperature to restrict the formation of oxides of nitrogen.

VEC points out in Figure 6-2 that air is approximately 21% oxygen, 78% nitrogen, and 1% other harmless gases. Nitrogen is the gas we want to control. Under atmospheric conditions nitrogen is inert and will not react with other gases, so it passes through the combustion process unchanged. However, above 2500°F or 1371°C when air is subjected to hot combustion pressure, nitrogen is no longer inert. The nitrogen combines with oxygen to form a variety of other gases called oxides of nitrogen, all grouped together under the term NO_x.

A function of the exhaust gas recirculation system is to reduce combustion temperatures by diluting the air/fuel mixture within the intake manifold with regulated amounts of exhaust gases. This process is shown in Figure 6-3. These exhaust gases will not support combustion by

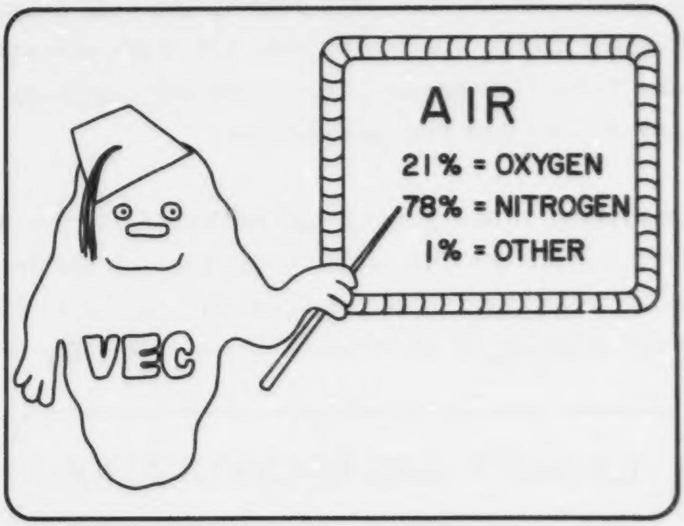
AIR
21% = OXYGEN
78% = NITROGEN
1% = OTHER
VEC

FIGURE 6-2

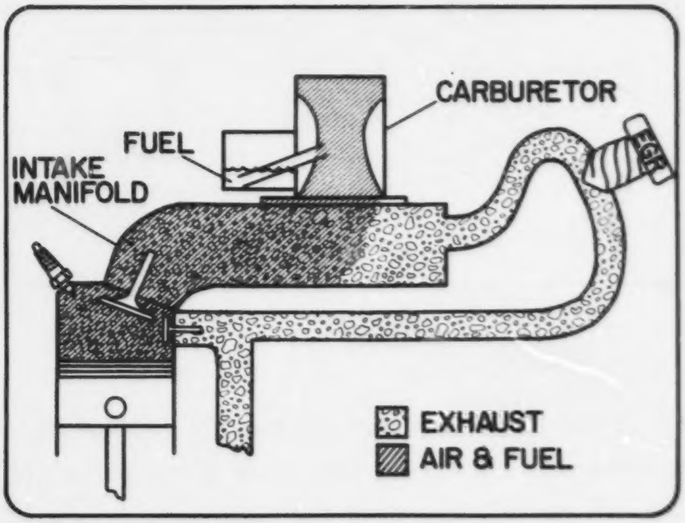
CARBURETOR
FUEL
INTAKE MANIFOLD
EGR
EXHAUST
AIR & FUEL

FIGURE 6-3

themsleves. This exhaust gas absorbs some of the heat of combustion and lowers combustion temperatures, thus reducing the formation of NO_x. The exhaust gas recirculation system recirculates approximately 6 to 14% of the unburned gases.

Exhaust gas recirculation was first used by the auto industry in 1972 to help the internal combustion engine meet the clean air standards. Federal Environmental Protection Agency has established standards that regulate the amount of NO_x emitted from automobiles.

The main components of the exhaust gas recirculation system are a flow control device called the EGR valve and an Exhaust Gas Recirculation Coolant Temperature Override switch, commonly called an EGR-CTO, and necessary connecting hoses as shown in Figure 6-4. The connecting hoses route vacuum to the EGR valve through the EGR-CTO switch. This allows the Coolant Temperature Override switch to block or unblock the vacuum source to the EGR valve, depending upon the temperature of the engine coolant.

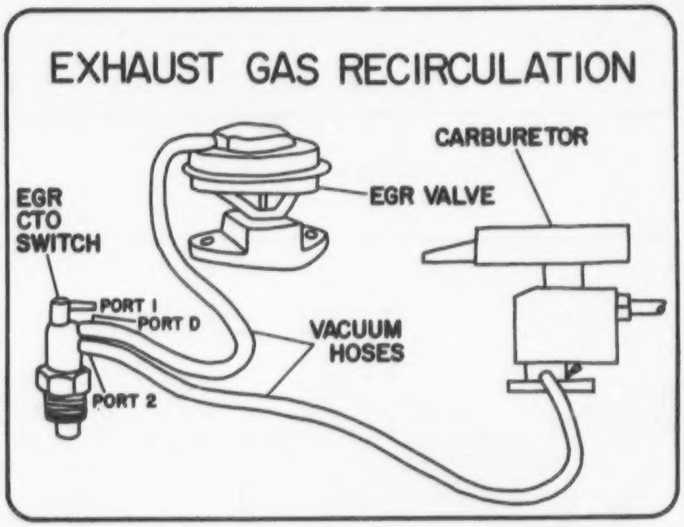

FIGURE 6-4

Let's take a closer look at the EGR valve and the EGR-CTO switch. First, the EGR valve (Figure 6-5) is a simple vacuum opened - spring closed valve, A coiled spring located above a flexible diaphragm holds the valve in a normally closed position. There is a vacuum nipple to accept vacuum, and a pintle which is simply a metering rod connected to the diaphragm.

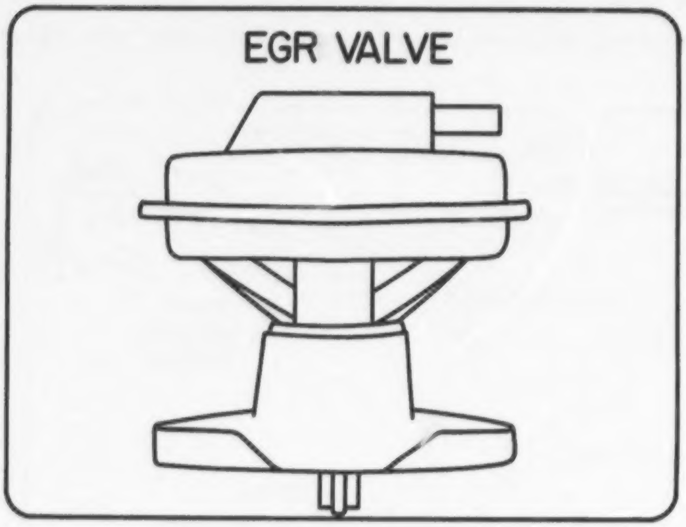

FIGURE 6-5

With no vacuum, the valve is closed. The pintle rests on a seat at the valve bottom to prevent exhaust gas from flowing through the valve as illustrated in Figure 6-6.

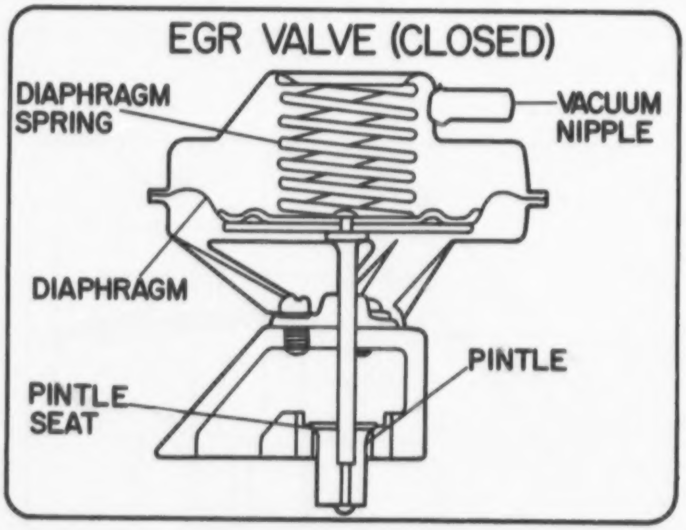
EGR VALVE (CLOSED)
DIAPHRAGM SPRING
VACUUM NIPPLE
DIAPHRAGM
PINTLE
PINTLE SEAT

FIGURE 6-6

During engine operation, vacuum is supplied to the valve vacuum nipple.

This vacuum shown by VEC draws the diaphragm upwards overcoming the spring force and pulling the pintle off its seat to open the valve (Figure 6-7.)

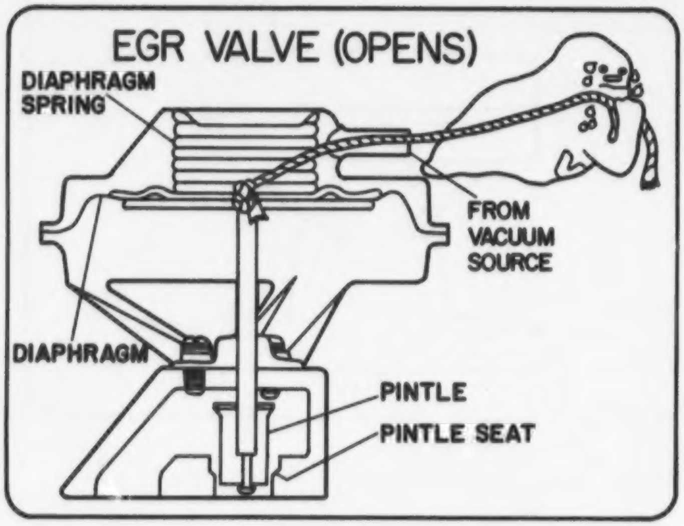
EGR VALVE (OPENS)
DIAPHRAGM SPRING
FROM VACUUM SOURCE
DIAPHRAGM
PINTLE
PINTLE SEAT

FIGURE 6-7

Exhaust gas is moved by engine intake manifold vacuum from the exhaust system through the pintle opening and valve passage. This exhaust gas is mixed in the intake manifold with the fresh air/fuel mixture as shown in Figure 6-8.

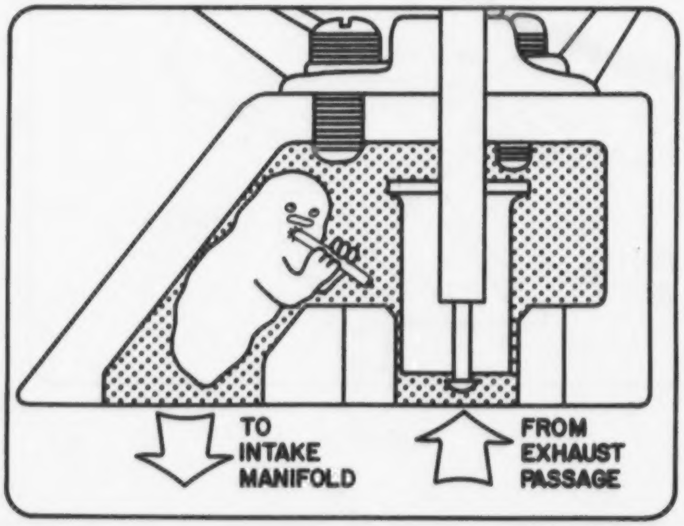
TO INTAKE MANIFOLD
FROM EXHAUST PASSAGE

FIGURE 6-8

The EGR-Coolant Temperature Override switch is another component in the exhaust gas recirculation system. This switch (Figure 6-9) is a simple temperature sensitive vacuum switch that allows the vacuum to be controlled according to the engine coolant temperature. At low temperature, the ball in the switch blocks vacuum at the lower port from reaching the center port which is connected to the EGR valve. When coolant temperature rises, the expansion in the lower chamber pushes up on the shaft that unseats the ball allowing vacuum to be supplied to the EGR valve. This improves driveability during the warm-up period.

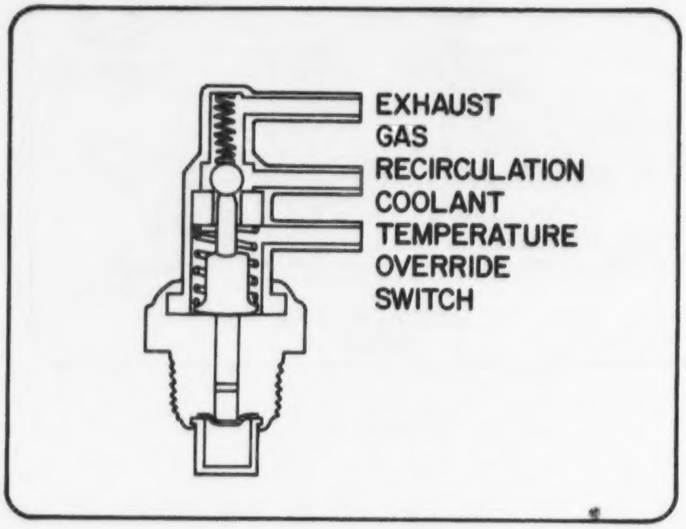

FIGURE 6-9

The exhaust gas recirculation system does not operate at idle or at full throttle because of low vacuum. The addition of exhaust gases during these modes would cause rough idle and limit maximum performance at full throttle.

Two methods are used to regulate the amount of exhaust gases going into the intake manifold. They are the floor jet method and floor entry method. The floor jet system (Figure 6-10) meters exhaust gases through two stainless steel jets in the intake manifold directly beneath the carburetor primary throttle bores. Intake manifold vacuum continually

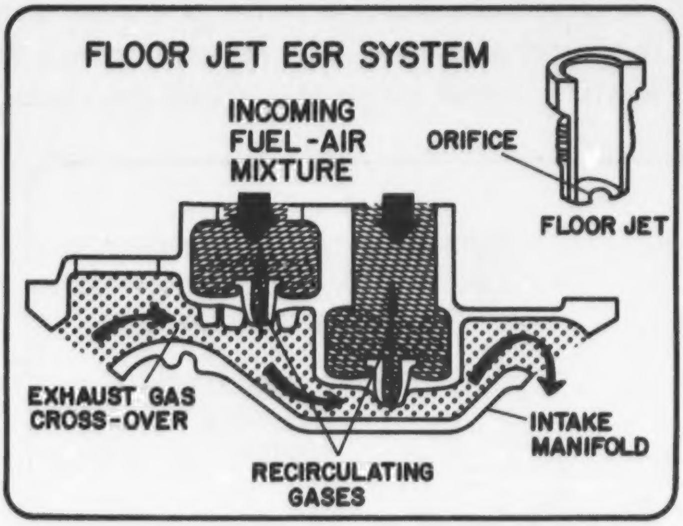
FLOOR JET EGR SYSTEM
INCOMING FUEL-AIR MIXTURE
ORIFICE
FLOOR JET
EXHAUST GAS CROSS-OVER
INTAKE MANIFOLD
RECIRCULATING GASES

FIGURE 6-10

draws exhaust gases through the jets but the amount of flow depends upon the amount of vacuum, size of the floor jets and the amount of exhaust back pressure.

The other method for permitting exhaust gas entry into the intake manifold is the floor entery method (Figure 6-11). As you can see, the EGR valve

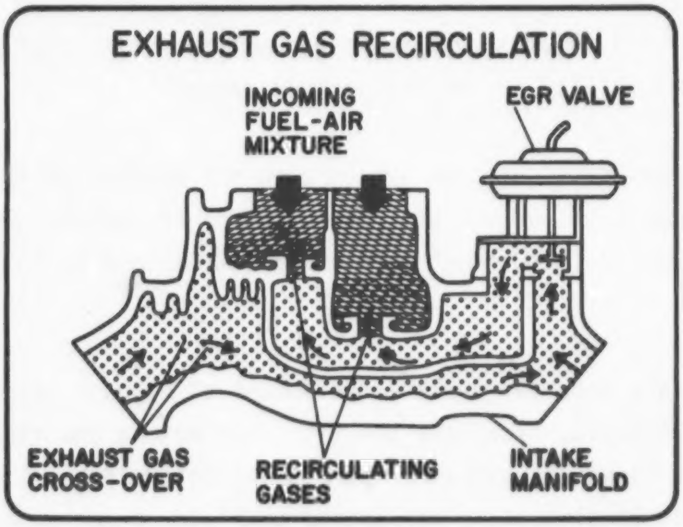
EXHAUST GAS RECIRCULATION
INCOMING FUEL-AIR MIXTURE
EGR VALVE
EXHAUST GAS CROSS-OVER
RECIRCULATING GASES
INTAKE MANIFOLD

FIGURE 6-11

allows the exhaust gases to reach the opening in the floor and enter the intake manifold. The difference between floor jet and floor entry method is the floor entry opening does not meter the gases. The EGR valve regulates the amount of exhaust gases entering the intake manifold.

Remember - the purpose of the EGR system is to supply in proper proportions, exhaust gas to the air/fuel mixture. This dilution lowers peak combustion temperatures and reduces NO_x emissions.

CHAPTER 7

SPARK CONTROL

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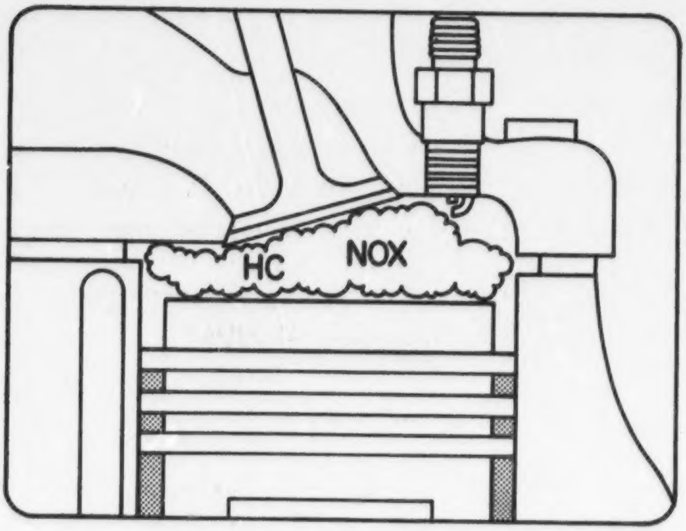

FIGURE 7-1

The purpose of the spark control timing system is to control the advance and retard of the spark to improve combustion and reduce the formation of NO_x and the HC emissions.

Retarded spark increases the exhaust gas temperature which promotes additional burning of the hydrocarbons (HC) in the exhaust manifold (Figure 7-2).

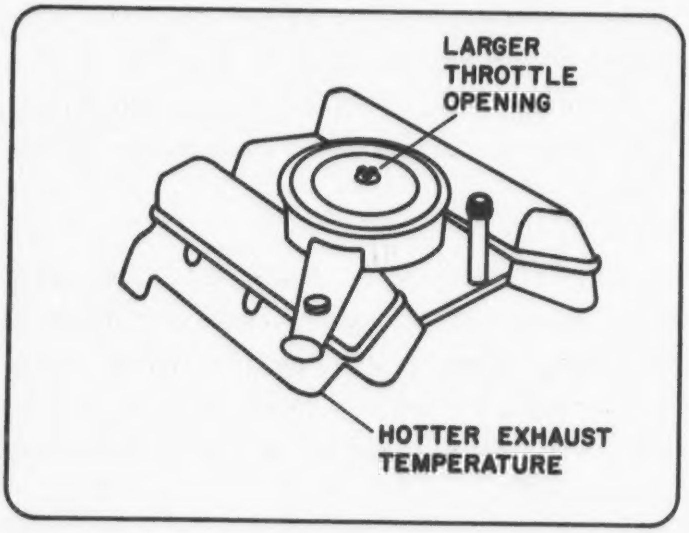
LARGER
THROTTLE
OPENING
HOTTER EXHAUST
TEMPERATURE

FIGURE 7-2

Retarded spark at idle also requires a larger throttle opening to obtain the desired idle speed. This results in more air entering the combustion chamber during idle.

It is important to note that vacuum from the engine can be sensed at different places in the carburetor as shown in Figure 7-3. Intake manifold vacuum is sensed below the throttle plate; therefore, vacuum is available at idle. Ported vacuum is sensed above the throttle plate and vacuum is not available until the throttle plate is in an off idle position. Venturi vacuum is initiated when greater amounts of air pass through the venturi portion of the carburetor. This vacuum may reach a maximum of only 3" to 4" Hg.

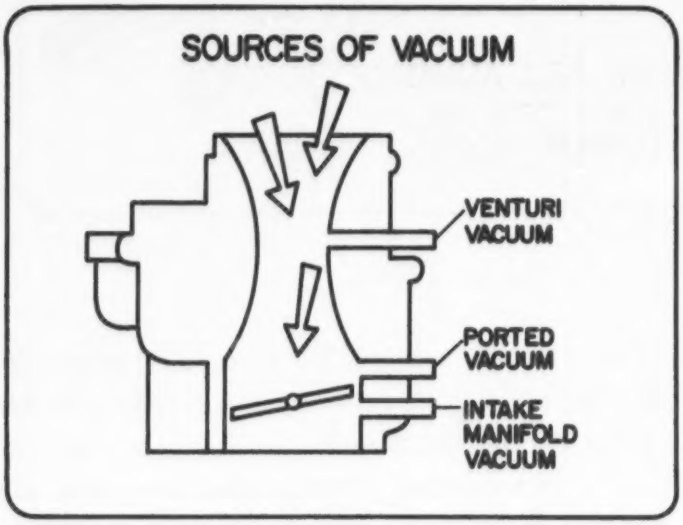

FIGURE 7-3

Prior to the introduction of the spark control system, vacuum was allowed to act directly on the vacuum advance unit on the distributor. The control of vacuum either being allowed or denied to the distributor is the main purpose of the vacuum solenoid valve (Figure 7-4). This valve will either allow or stop any vacuum to the distributor advance unit.

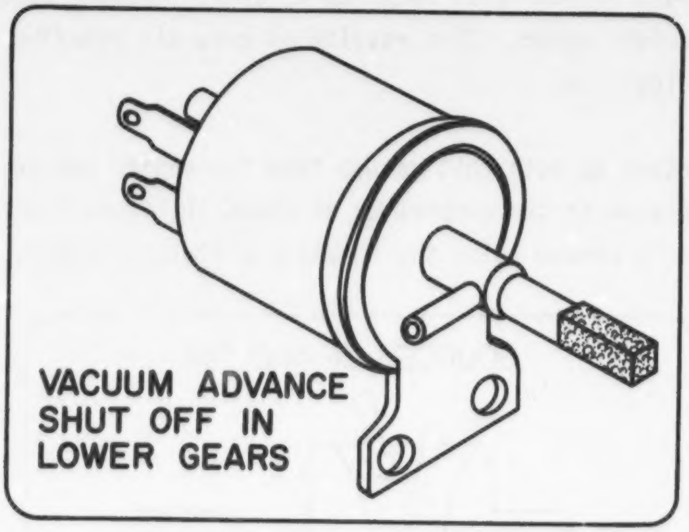

FIGURE 7-4

The vacuum solenoid valve is basically an on/off vacuum switch. This valve is controlled electrically through a transmission switch. When electrical current is applied through the contacts, the coil built into the solenoid valve is energized. This closes the valve and blocks vacuum from the carburetor to the solenoid valve distributor port. There is a filter on the end of the vacuum solenoid valve which allows atmospheric pressure to enter the valve and bleed the distributor vacuum hose of any vacuum. The vacuum solenoid valve is located in the vacuum line between the vacuum source and the vacuum advance unit on the distributor. A cross section of the vacuum solenoid valve is shown in Figure 7-5.

The vacuum solenoid valve is controlled by a transmission switch. The transmission switch is used on both the manual transmission and automatic transmissions. The manual transmission switch is open in high gear only. The automatic transmission switch is open at approximately 35 MPH or high gear. See Figure 7-6 for an illustration of the manual and automatic transmission switch.

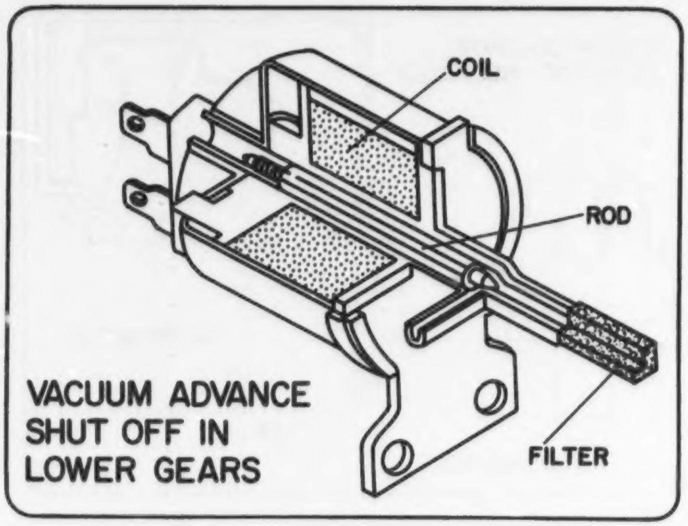
COIL
ROD
FILTER
VACUUM ADVANCE SHUT OFF IN LOWER GEARS

FIGURE 7-5

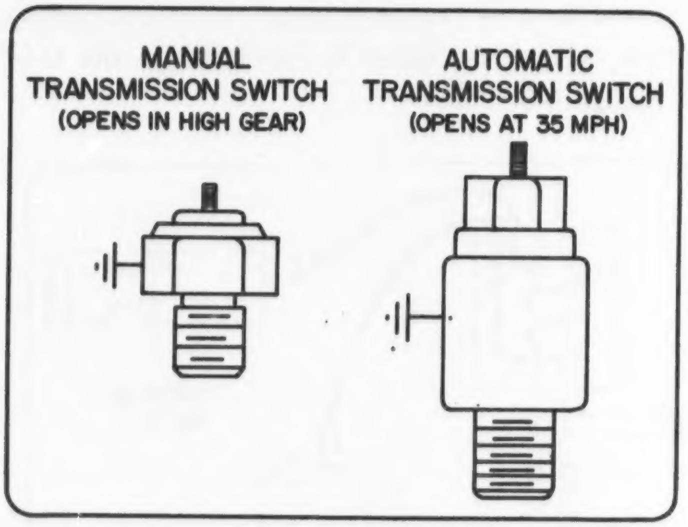
MANUAL TRANSMISSION SWITCH (OPENS IN HIGH GEAR)
AUTOMATIC TRANSMISSION SWITCH (OPENS AT 35 MPH)

FIGURE 7-6

When the transmission switch opens, it breaks the ground circuit to the vacuum solenoid valve. When this ground circuit is broken, the vacuum solenoid valve is de-energized pulling the plunger off its seat (Figure 7-7) and vacuum is allowed to act on the distributor advance unit. When the transmission switch is closed, the ground circuit is complete, the vacuum solenoid valve is energized pulling the plunger against its seat, and vacuum is denied to the distributor advance unit.

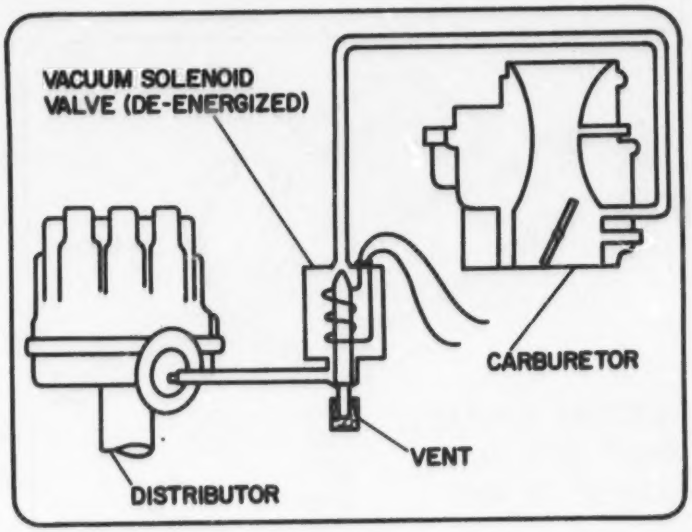
VACUUM SOLENOID
VALVE (DE-ENERGIZED)
CARBURETOR
VENT
DISTRIBUTOR

FIGURE 7-7

The vacuum solenoid valve has two electrical connections. One is connected to the ignition switch, the other is connected to the transmission switch as shown in Figure 7-8.

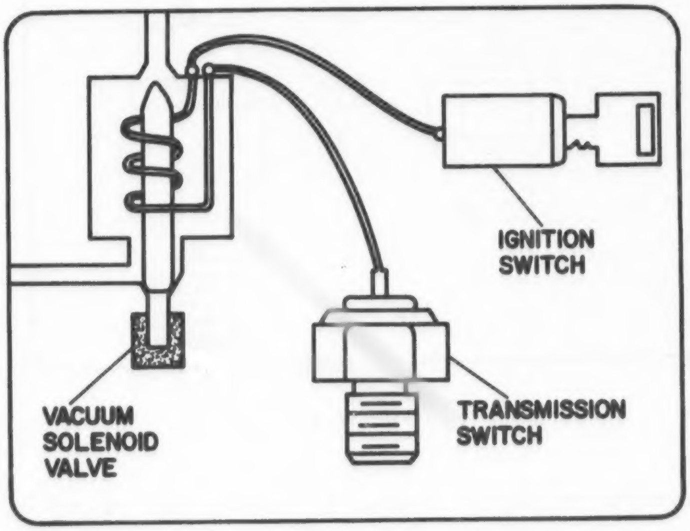
IGNITION
SWITCH
VACUUM
SOLENOID
VALVE
TRANSMISSION
SWITCH

FIGURE 7-8

Figure 7-9 shows the vacuum solenoid valve connected between the carburetor and the distributor with its terminals connected to the ignition switch and to the transmission switch. You will notice that vacuum is being allowed through the vacuum solenoid valve, thus the transmission swtich is open and the ground circuit has been broken or the vacuum solenoid valve has been de-energized.

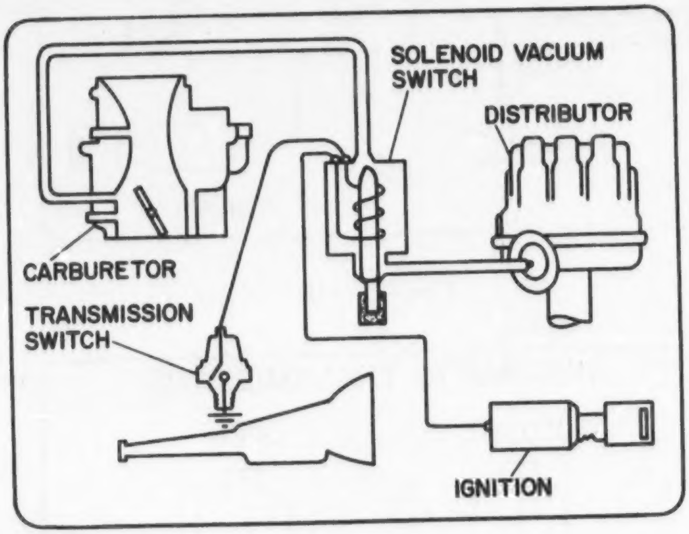

FIGURE 7-9

When the transmission switch is closed, the vacuum solenoid valve is energized, thus blocking or denying vacuum from the carburetor to the distributor (Figure 7-10). The vacuum solenoid valve will allow vacuum to pass if electric current is being denied to the vacuum solenoid valve. There are exceptions to this. Some vacuum solenoid valves allow vacuum advance to the distributor when they are energized.

Let's take a little closer look at a switch used with automatic transmissions. When the transmission is in low gear or the vehicle speed is below 35 MPH, the switch is closed, completing the ground circuit; however, when the vehicle exceeds 35 MPH, the switch opens, breaking the ground circuit, de-energizing the vacuum solenoid valve (Figure 7-11). This opening and closing of the automatic transmission switch is regulated

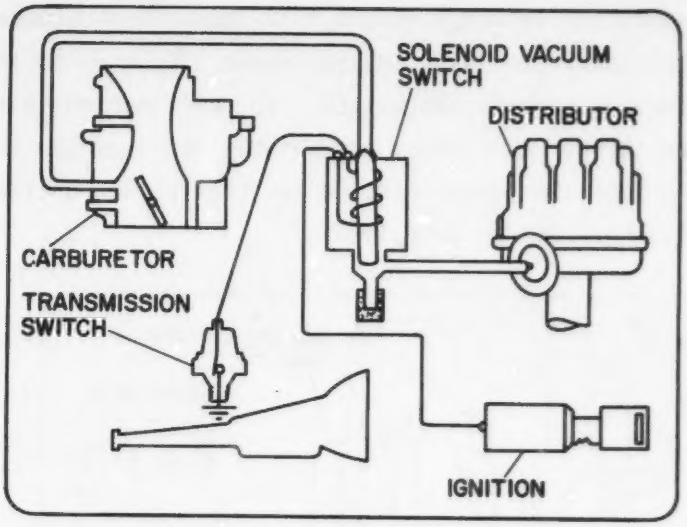
SOLENOID VACUUM SWITCH
DISTRIBUTOR
CARBURETOR
TRANSMISSION SWITCH
IGNITION

FIGURE 7-10

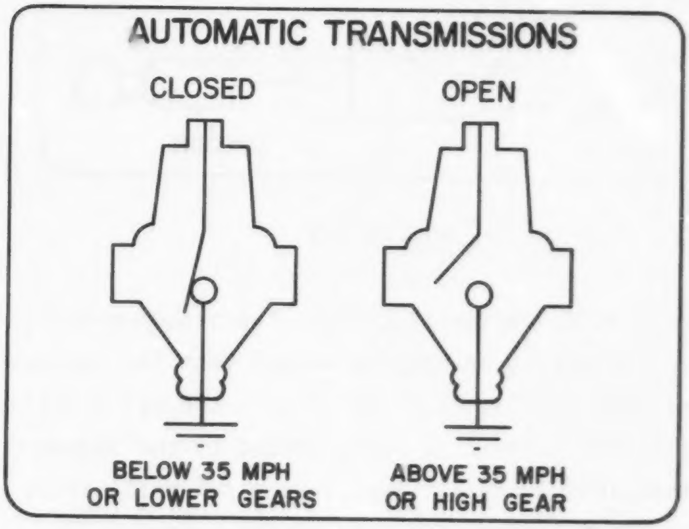
AUTOMATIC TRANSMISSIONS
CLOSED
OPEN
BELOW 35 MPH OR LOWER GEARS
ABOVE 35 MPH OR HIGH GEAR

FIGURE 7-11

by hydraulic pressure in the transmission. The switch may be connected in the governor circuit, or to the direct clutch of the automatic transmission, depending upon the type of transmission.

The manual transmission switch basically performs the same function. It is closed in low gears, thus completing the ground circuit to the vacuum solenoid valve (Figure 7-12) and in high gear, the manual transmission switch is open. This de-energizes the vacuum solenoid valve by breaking the ground circuit. This opening and closing of the manual transmission switch is performed by the gear shift linkage.

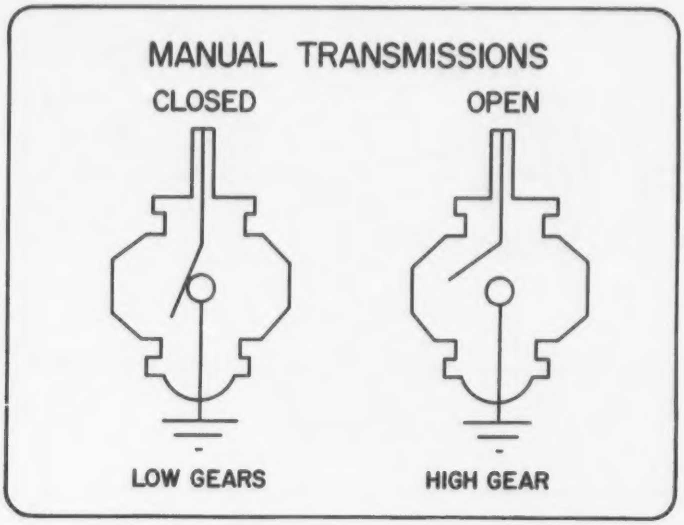

FIGURE 7-12

During the time vacuum is being denied to the advance unit on the distributor, the vacuum trapped between the vacuum solenoid valve and the vacuum advance unit on the distributor is purged with atmospheric pressure. This is done through a vent opening on the vacuum solenoid valve, as illustrated in Figure 7-13. The vent opening usually has a sponge filter to prevent foreign particles from entering the vacuum solenoid valve. The trapped vacuum, between the solenoid valve and the advance unit, must be released to allow the advance unit to return to vacuum off position.

To improve cold engine driveability, a CTO (cold temperature override) switch has been installed in the transmission control spark system (Figure 7-14). The purpose of this switch is to allow manifold vacuum

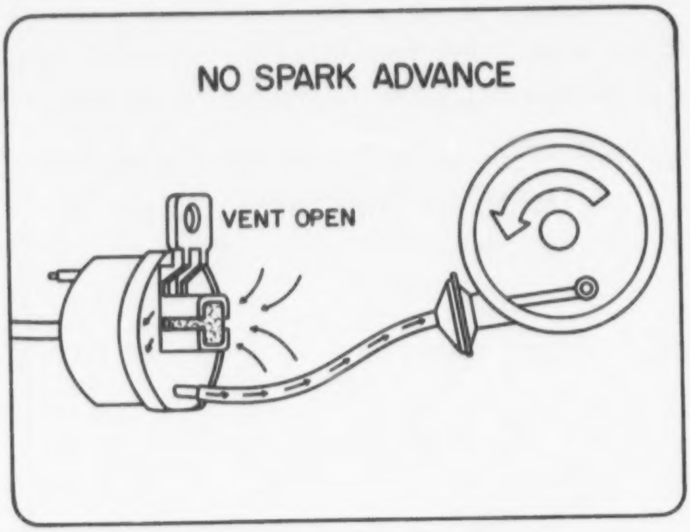
NO SPARK ADVANCE
VENT OPEN

FIGURE 7-13

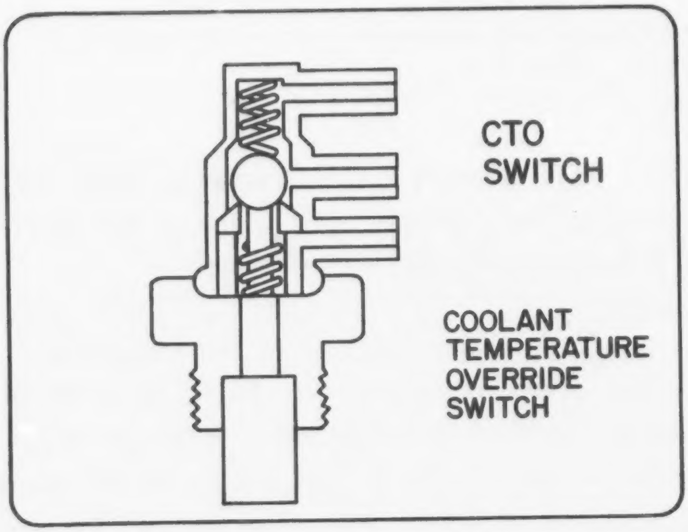
CTO
SWITCH
COOLANT
TEMPERATURE
OVERRIDE
SWITCH

FIGURE 7-14

to the advance unit on the distributor when the engine coolant temperature is below approximately 160°F. This CTO switch is a temperature sensitive vacuum switch that allows the vacuum to be controlled according to the engine coolant temperature.

At cool temperatures, the CTO switch prevents carburetor ported vacuum, at the lower port, from reaching the center port which is connected to the distributor vacuum control unit. The upper port is open to the center port which is connected to the distributor vacuum control unit. This allows full manifold vacuum to the vacuum advance unit on the distributor when the engine coolant temperature is below approximately 160°F (Figure 7-15). This improves driveability during the warm-up periods.

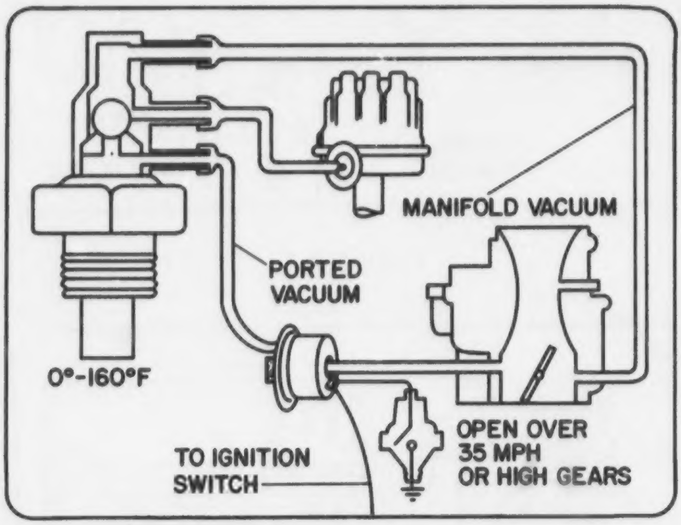

FIGURE 7-15

When coolant temperature rises, the expansion of the material in the lower chamber of the switch pushes up on the ball, blocking off manifold vacuum from the top port and allowing ported vacuum from the bottom port to enter the center port. This center port is connected to the vacuum advance unit on the distributor. This is the position of the CTO switch under normal operating conditions (Figure 7-16).

Proper routing of vacuum hoses is very important because they help determine the proper operation of the transmission control spark system. Figure 7-17 shows the proper routing of vacuum hoses. On the CTO (cold temperature override) switch, port 1, the upper port is connected to intake manifold vacuum. Port D, which controls the device, is connected

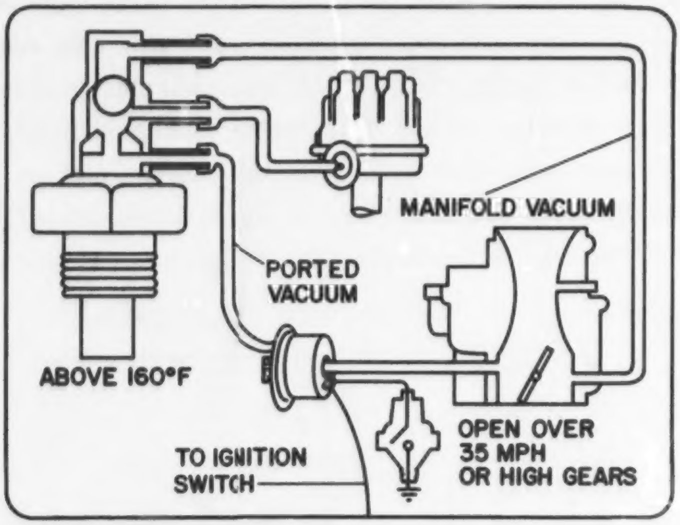
MANIFOLD VACUUM
PORTED VACUUM
ABOVE 160°F
OPEN OVER 35 MPH OR HIGH GEARS
TO IGNITION SWITCH

FIGURE 7-16

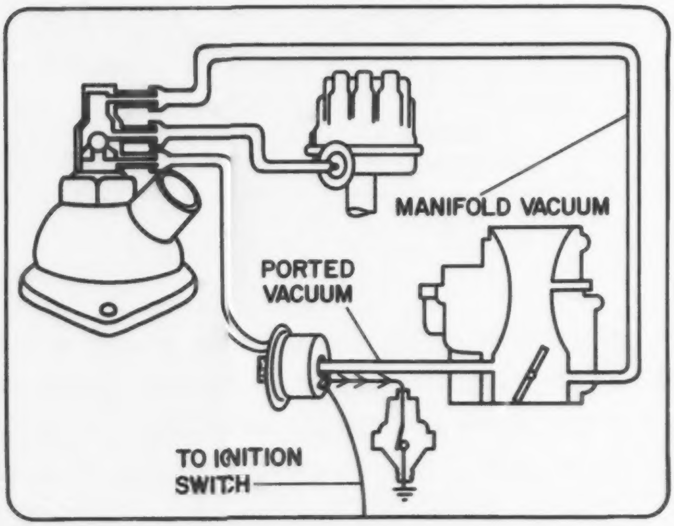
MANIFOLD VACUUM
PORTED VACUUM
TO IGNITION SWITCH

FIGURE 7-17

to the vacuum advance unit on the distributor and the lower port, port 2, is connected to carburetor ported vacuum. The cold temperature override switch is usually mountedvery close to the thermostat housing to sense the highest coolant tempeature.

Let's review the transmission control spark. The vacuum solenoid valve is connected bewteen port 2 of the CTO switch and the carburetor ported vacuum. From the terminal leads of the vacuum solenoid valve we have connected the transmission switch and the ignition switch. Port D of the CTO switch is connected to the distributor and port 1 to the manifold vacuum. If temperatures are below 160°F, the ball in the CTO switch will be in a lower position, thus blocking off any vacuum that might be coming from carburetor ported vacuum (Figure 7-18). If the automobile is running between 0 and 35 MPH or in lower gears, the tranmsission switch is closed, thus completing the ground circuit and energizing the vacuum solenoid valve. The vacuum solenoid valve being energized will then block vacuum from the carburetor going to the CTO switch.

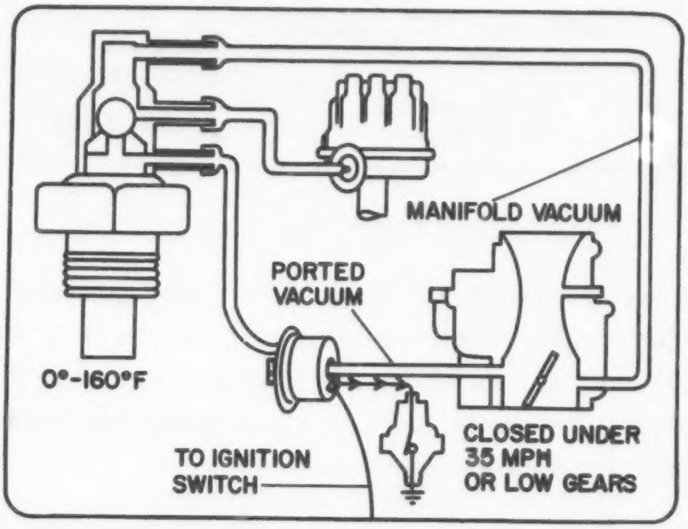

FIGURE 7-18

Remember, there is a vent (Figure 7-19) in the vacuum solenoid valve to allow atmospheric pressure to purge any vacuum remaining between the vacuum solenoid valve and the vacuum advance unit on the distributor.

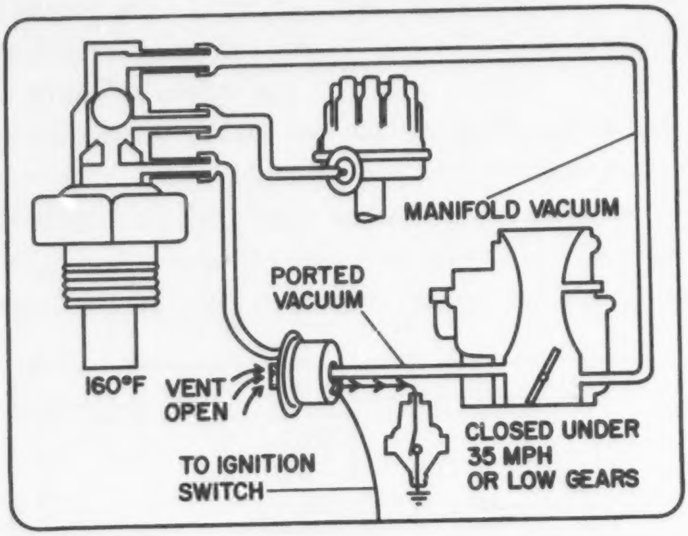
MANIFOLD VACUUM
PORTED VACUUM
160°F
VENT OPEN
TO IGNITION SWITCH
CLOSED UNDER 35 MPH OR LOW GEARS

FIGURE 7-19

Some transmission control spark systems are equipped with a hot override switch (Figure 7-20). The purpose of this hot override switch is to provide full manifold vacuum to the advance unit on the distributor when coolant temperatures reach 225°F. This advances the spark, resulting in a faster idle for more efficient cooling.

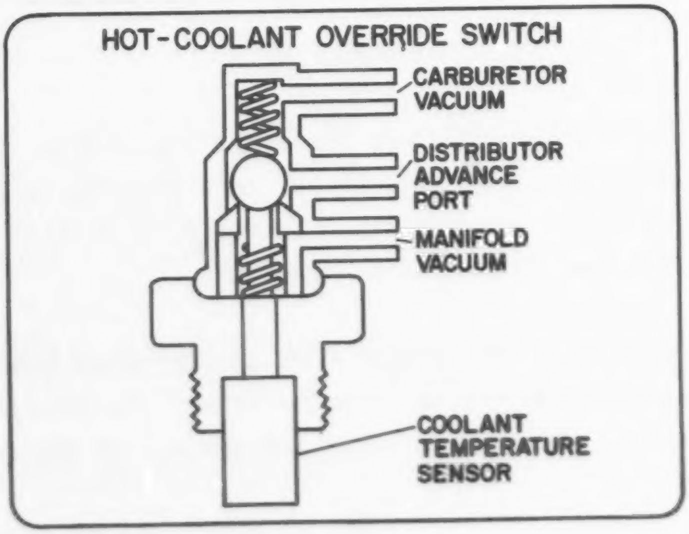
HOT-COOLANT OVERRIDE SWITCH
CARBURETOR VACUUM
DISTRIBUTOR ADVANCE PORT
MANIFOLD VACUUM
COOLANT TEMPERATURE SENSOR

FIGURE 7-20

The hot override switch (Figure 7-21) is basically constructed the same as the CTO switch just discussed. However, the hot override switch has intake manifold vacuum routed to the lower port, port 2. Carburetor ported vacuum is connected to the upper port, port 1. The middle port, or port D, is connected to the lower port of the CTO switch. Let's take a closer look at the vacuum routings and see what happens as the engine coolant temperature goes from 0 to 225°F.

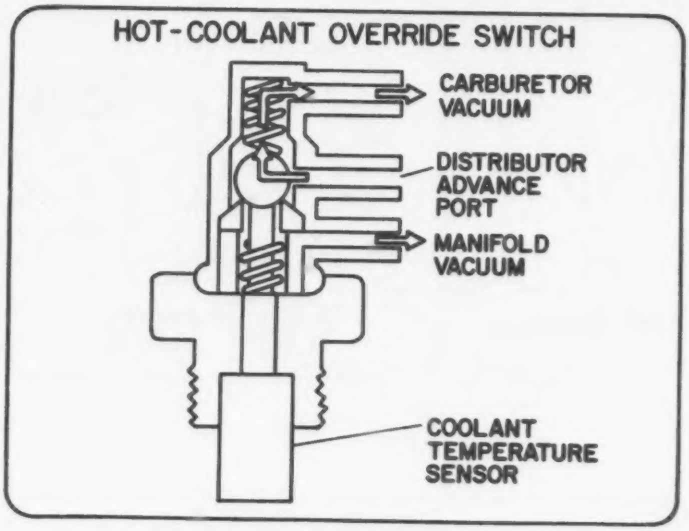

FIGURE 7-21

With the engine coolant above 160°F, the ball of the CTO switch moves upward, blocking off any intake manifold vacuum at the top port. When engine coolant is between approximately 160°F and 225°F (Figure 7-22), ported vacuum is routed to the hot override switch top port and out port D to the lower port on the CTO switch. Ported vacuum is now available at port D on the CTO switch which is connected to the vacuum advance unit on the distributor.

When the coolant temperature is above 225°F (Figure 7-23), the ball in the hot override switch moves upward to block off the top port. This upward movement opens a passage and allows manifold vacuum to pass through

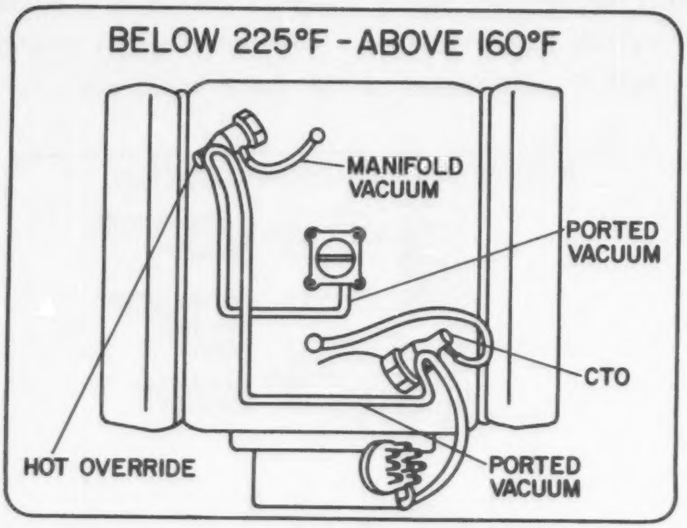
BELOW 225°F - ABOVE 160°F
MANIFOLD VACUUM
PORTED VACUUM
CTO
HOT OVERRIDE
PORTED VACUUM

FIGURE 7-22

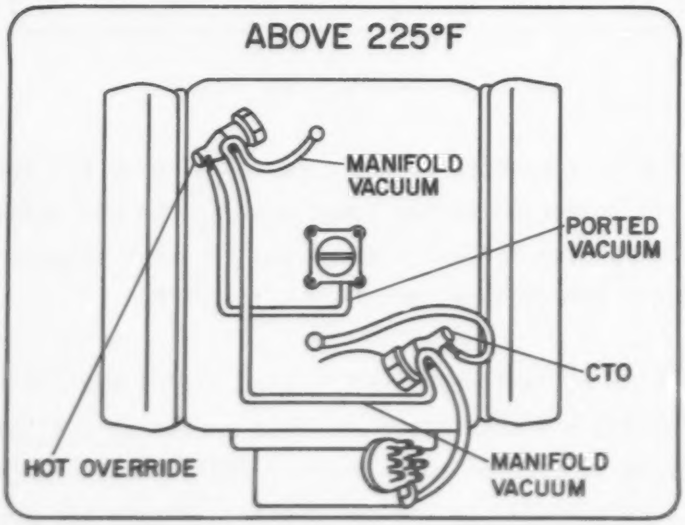
ABOVE 225°F
MANIFOLD VACUUM
PORTED VACUUM
CTO
HOT OVERRIDE
MANIFOLD VACUUM

FIGURE 7-23

the hot override switch and CTO switch to the vacuum advance unit on the distributor With full manifold vacuum being applied to the vacuum advance unit on the distributor, engine RPM will increase. The increase in engine RPM allows the fan to draw more air through the radiator, as well as increase coolant flow. This will reduce coolant temperature to safe operating levels.

Figure 7-24 shows a transmission control spark system equipped with a hot override switch and a cold temperature override switch. The vacuum solenoid valve is installed in the vacuum line between carburetor ported vacuum and the upper port of the hot override switch.

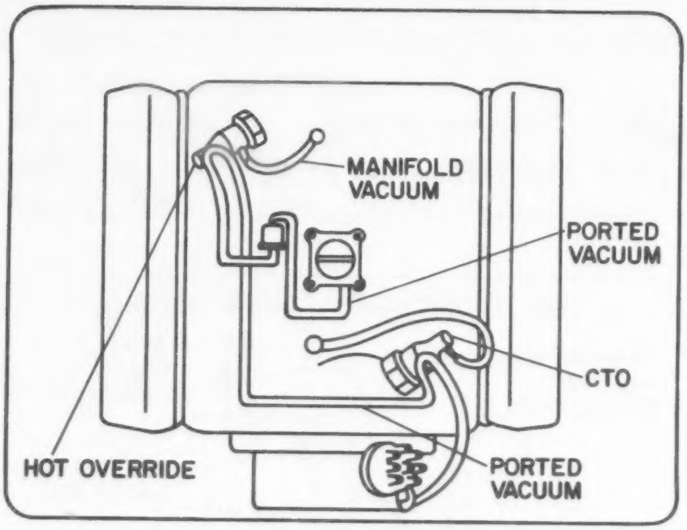
MANIFOLD VACUUM
PORTED VACUUM
CTO
HOT OVERRIDE
PORTED VACUUM

FIGURE 7-24

General Motor's thermal vacuum switch (Figure 7-25) operates the same as the hot override switch, except the internal structure is a little different. They use a small piston with seals instead of the ball. Also the

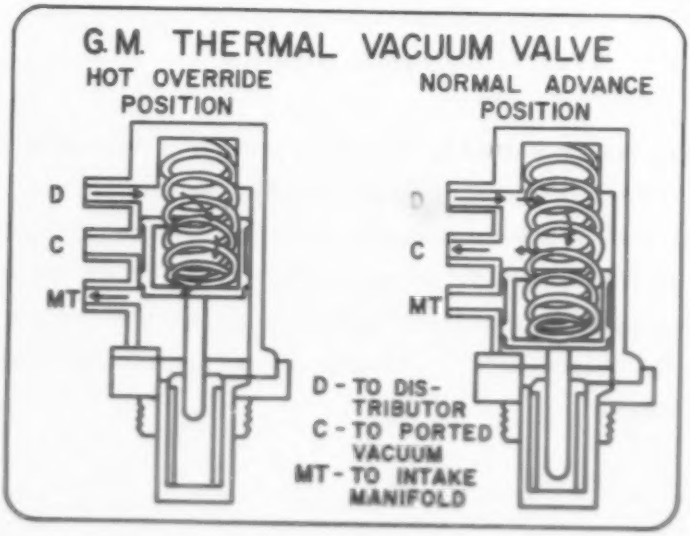
G.M. THERMAL VACUUM VALVE
HOT OVERRIDE POSITION
NORMAL ADVANCE POSITION
D
C
MT
D
C
MT
D - TO DISTRIBUTOR
C - TO PORTED VACUUM
MT - TO INTAKE MANIFOLD

FIGURE 7-25

internal routing is slightly different. Port D, or the upper port, is connected to the distributor and the lower port, MT, is connected to intake manifold and the center port, port C, is connected to the carburetor ported vacuum. Even though most transmissions that control spark systems are alike, it is important to check the manufacturer's specifications and service manuals for each specific engine you are working on.

Dual diaphragm distributors (Figure 7-26) are also used as a means to retard the spark during deceleration and idle. This vacuum unit has a movable advance diaphragm as shown, which allows the spark to be retarded at idle and advance normally at part throttle. Two chambers are used along with two calibrated springs which allow the ported vacuum signal to overcome manifold vacuum under part throttle conditions. To test the operation of the retard diaphragm, simply connect manifold vacuum to the diaphragm closest to the distributor and watch the timing marks. The timing should retard 6-10°. Advance is tested at 2500 RPM with both lines connected.

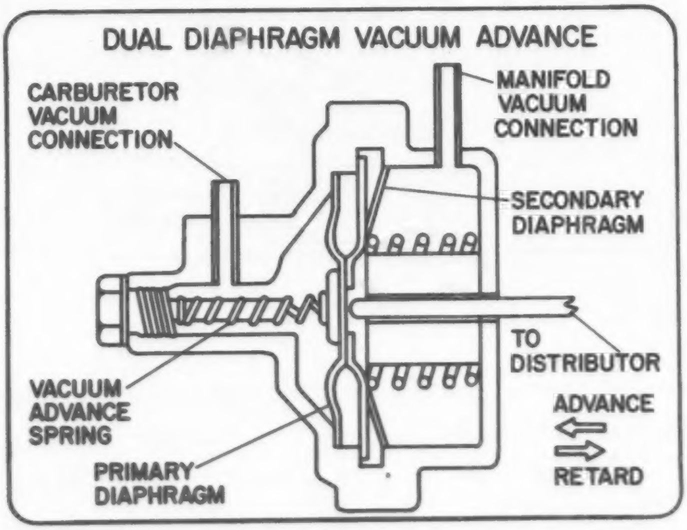
DUAL DIAPHRAGM VACUUM ADVANCE
CARBURETOR VACUUM CONNECTION
MANIFOLD VACUUM CONNECTION
SECONDARY DIAPHRAGM
TO DISTRIBUTOR
ADVANCE
RETARD
VACUUM ADVANCE SPRING
PRIMARY DIAPHRAGM

FIGURE 7-26

On some engines, advanced spark timing is required during periods of deceleration for the purpose of preventing backfiring or popping noise in the engine exhaust system. The distributor advance control or deceleration valve shown in Figure 7-27 is added to the advance diaphragm vacuum supply line for the specific purpose of advancing spark timing during engine deceleration.

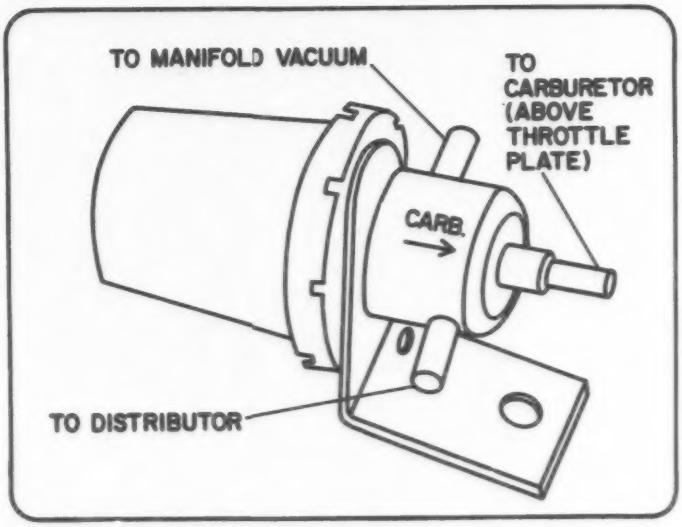
TO MANIFOLD VACUUM
TO CARBURETOR (ABOVE THROTTLE PLATE)
CARB.
TO DISTRIBUTOR

FIGURE 7-27

Remember - the purpose of tie spark control timing system is to control the advance and retard of tie spark to improve combustion and reduce the formation of NO_x and the HC emissions.

CHAPTER 8

CATALYTIC CONVERTER SYSTEM

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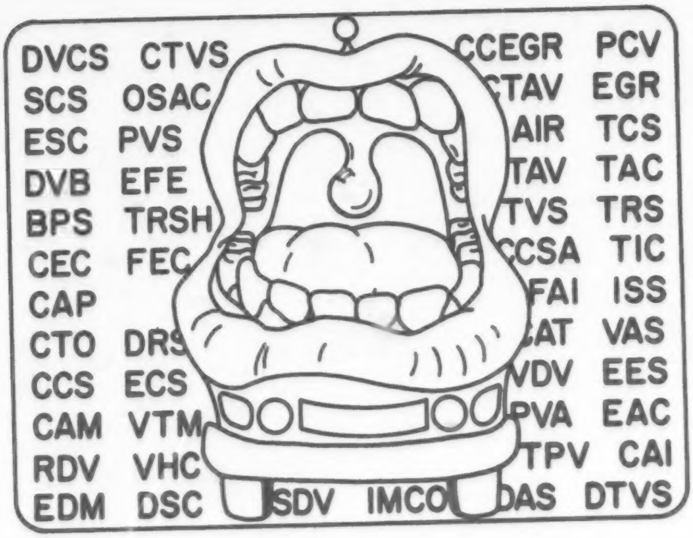

DVCS
CTVS
CCEGR
PCV
SCS
OSAC
CTAV
EGR
ESC
PVS
AIR
TCS
DVB
EFE
TAV
TAC
BPS
TRSH
TVS
TRS
CEC
FEC
CCSA
TIC
CAP
FAI
ISS
CTO
DRS
CAT
VAS
CCS
ECS
VDV
EES
CAM
VTM
PVA
EAC
RDV
VHC
TPV
CAI
EDM
DSC
SDV
IMCO
DAS
DTVS

FIGURE 8-1

The purpose of emissions control systems is to reduce the amounts of HC, CO and NO_x that are discharged to atmosphere from the automobile (Figure 8-1). Some of these devices control spark timing for more complete combustion; others prevent the escape of fumes and vapors and re-introduce these for further combustion. Other modifications control the air/fuel ratio so extra oxygen is available for more complete combustion. Let's see how the catalytic converter fits into the automotive emissions control program.

The automobile manufacturers found that a device called the catalytic converter would reduce HC and CO emissions to a value that would meet EPA requirements for 1975 and 1976. The catalytic converter would also allow engines to be retuned for more power, performance and better fuel economy.

Catalytic converter systems reduce the amount of hydrocarbons (HC) and carbon monoxide (CO) in the automobile exhaust by providing an additional area for oxidation or burning to occur as shown in Figure 8-2.

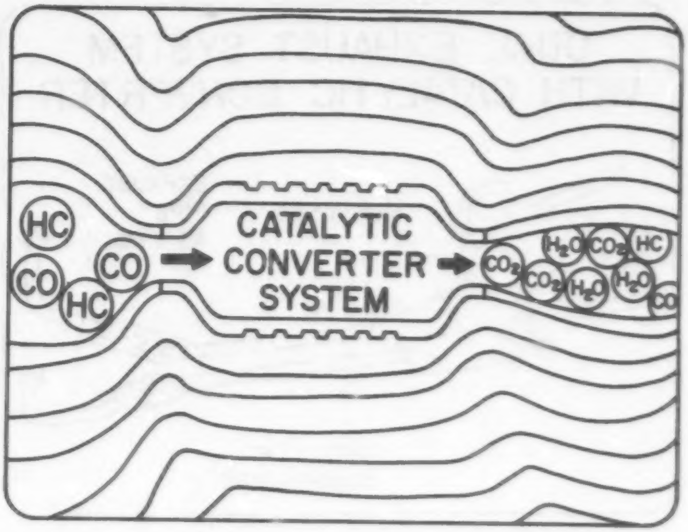

HC
CO
CO
HC
CATALYTIC CONVERTER SYSTEM
CO_2
H_2O
CO_2
HC
CO_2
H_2O
H_2O
CO

FIGURE 8-2

The catalytic converter looks like another muffler. It is located on the automobile exhaust system ahead of the muffler and fairly close to the exhaust manifold (Figure 8-3).

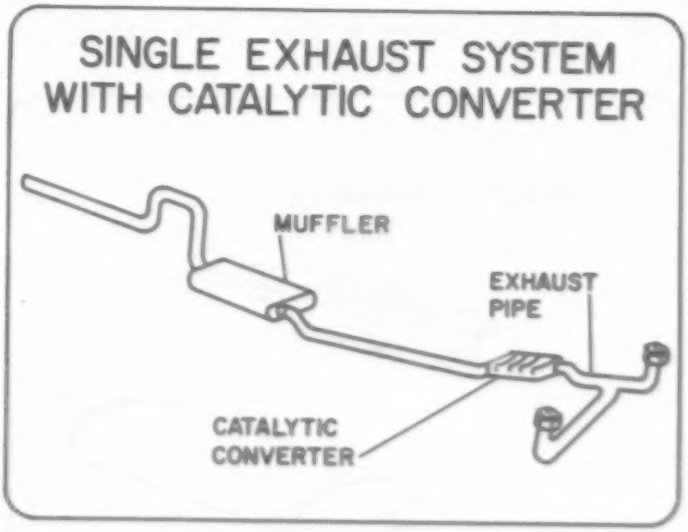

SINGLE EXHAUST SYSTEM WITH CATALYTIC CONVERTER
MUFFLER
EXHAUST PIPE
CATALYTIC CONVERTER

FIGURE 8-3

On vehicles with one exhaust pipe, one catalytic converter is used. If the vehicle has dual exhausts, two catalytic converters will normally be used (Figure 8-4).

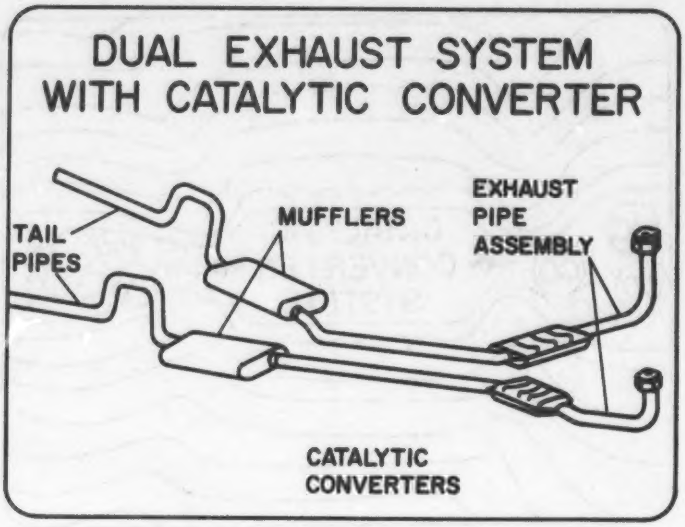

DUAL EXHAUST SYSTEM
WITH CATALYTIC CONVERTER
TAIL PIPES
MUFFLERS
EXHAUST PIPE ASSEMBLY
CATALYTIC CONVERTERS

FIGURE 8-4

Looking closer at the catalytic converter, one difference can be seen that distinguishes it from an ordinary muffler (Figure 8-5). That difference is that the shell or outer skin of the converter is made of stainless steel. Stainless steel is more durable and corrosion resistant than the metal used in ordinary muffler construction.

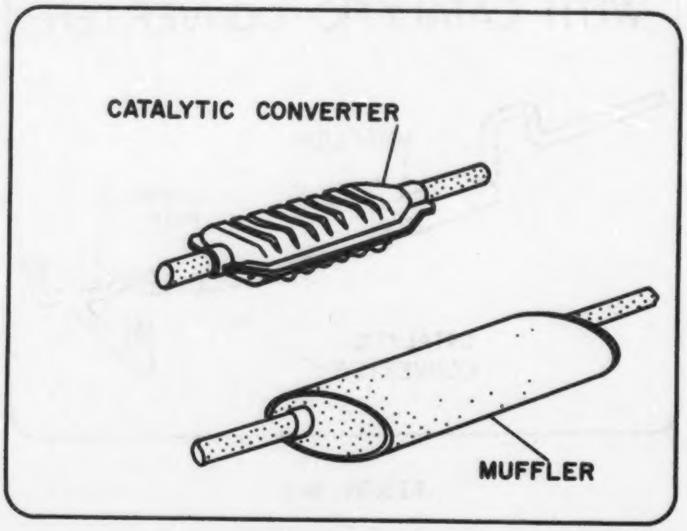

CATALYTIC CONVERTER
MUFFLER

FIGURE 8-5

There are two basic internal designs for catalytic converters: a monolith design and a pellet design.

As exhaust gases enter a monolith type catalytic converter (Figure 8-6), they first encounter a flow diffuser. The flow diffuser spreads or diffuses the exhaust gases for a more even flow through the next component which is the monolith catalytic converter element. Surrounding the monolith converter element is a stainless steel mesh. The purpose of this mesh is to cradle the monolith element and protect it from road shock.

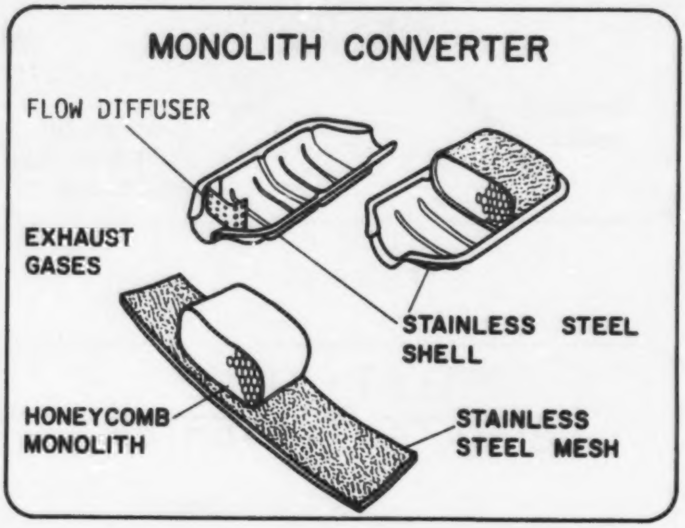


FIGURE 8-6

The monolith element is a honeycomb type design (Figure 8-7). The element has hundreds of cellular passages for the exhaust gases to flow through. The element is made of a ceramic material. A very thin coating of platinum and palladium is used to cover this cellular ceramic element.

The pellet style of catalytic converter (Figure 8-8) works in the same manner as the monolith converter. Rather than a ceramic monolith element, the pellet style converter uses small aluminum oxide pellets approximately 1/8" to 3/16" in diameter. These small aluminum oxide pellets are coated with a very thin layer of platinum and palladium.

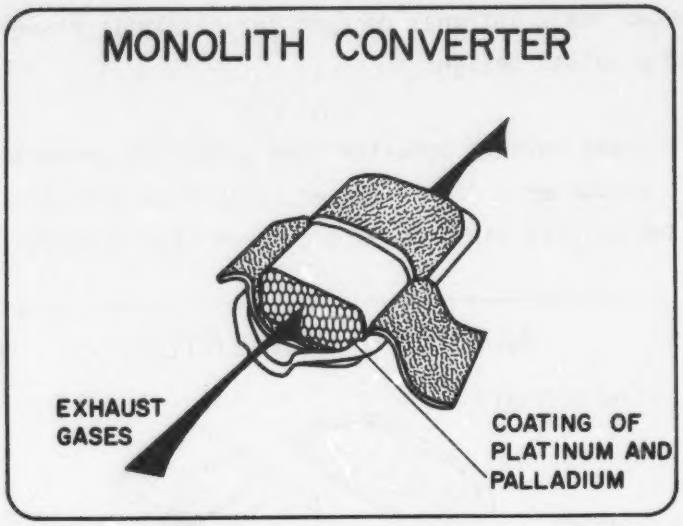

MONOLITH CONVERTER
EXHAUST GASES
COATING OF PLATINUM AND PALLADIUM

FIGURE 8-7

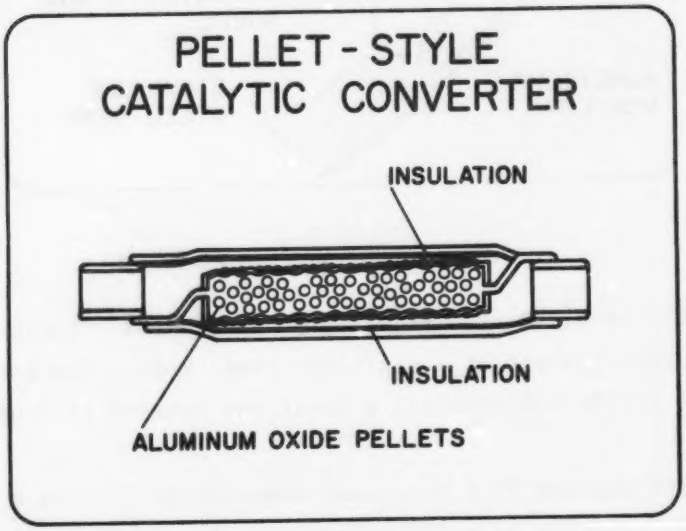

PELLET - STYLE CATALYTIC CONVERTER
INSULATION
INSULATION
ALUMINUM OXIDE PELLETS

FIGURE 8-8

The exhaust gases enter the pellet converter (Figure 8-9) and are directed upward by baffles. The only way for the exhaust gases to leave the converter is to flow downward, passing through the bed of pellets and then out of the converter to the muffler. The pellet bed is supported by baffle plates. There is also a layer of insulation that enclosed the baffles and pellet bed.

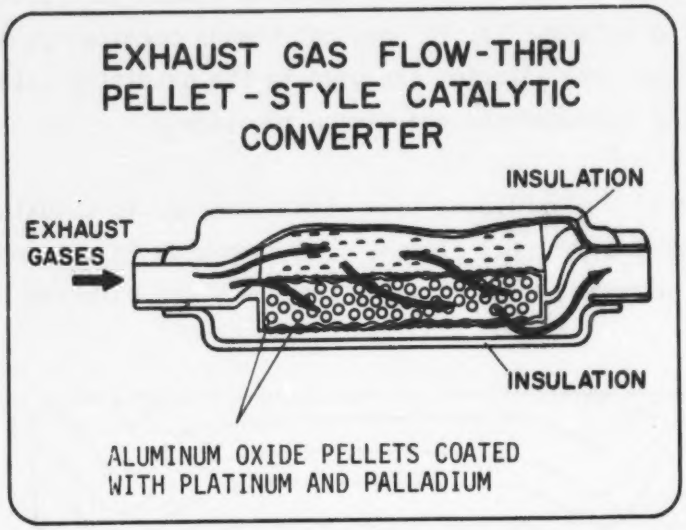

EXHAUST GAS FLOW-THRU
PELLET-STYLE CATALYTIC
CONVERTER
INSULATION
EXHAUST
GASES
INSULATION
ALUMINUM OXIDE PELLETS COATED
WITH PLATINUM AND PALLADIUM

FIGURE 8-9

Both types of catalytic converters perform efficiently but both have advantages and disadvantages. The monolithic converter is more resistant to damage from vibration and is physically smaller. Therefore, it heats up faster allowing it to perform its function sooner. The monolithic converter offers less resistantce to exhaust flow and therefore has less back pressure. The disadvantages of the monolithic types are: they are not repairable; they must be replaced; they are more expensive to build; and they require more platinum.

The pellet type converter design is repairable; the pellets can be replaced; it uses less platinum and therefore, is less expensive to build. The disadvantages of the pellet converter design are: they warm up slower because of their larger size; they offer more resistance to exhaust gas flow; and they are not quite as durable as the monolith design.

Platinum and palladium, used in both converters, are noble metals. These elements are used as the catalytic agents of the catalysts. Both types of converters use approximately 70% platinum and 30% palladium. Platinum is the better of the two as a catalyst, but is very expensive. Palladium is not as efficient as platinum, but is used to reduce the overall cost.

A catalyst is a substance used to speed up a chemical reaction. The nice thing about a catalyst is, it does not change chemically, nor is it used up. (Platinum and palladium are used in the oxidizing catalytic converter which reduces hydrocarbons and carbon monoxide.)

The purpose of the oxidizing catalytic converter is to oxidize or add oxygen to certain harmful elements and compounds in the exhaust gas (Figure 8-10). These harmful elements and compounds are oxidized to harmless compounds.

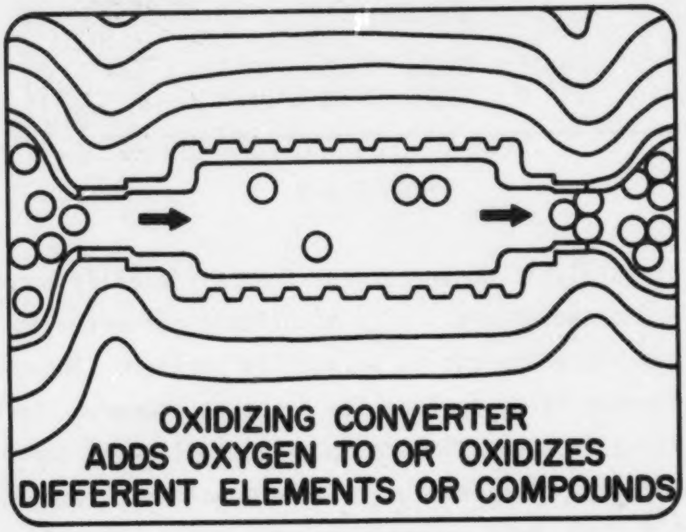


FIGURE 8-10

In automotive applications, the chemical compounds that require oxidizing are hydrocarbons (HC) and carbon monoxide (CO) as shown in Figure 8-11. The hydrocarbons (HC) are portions of unburned fuel. The carbon monoxide (CO) results when there is insufficient oxygen to completely oxidize carbon (C) atoms to carbon dioxide (CO_2).

In the catalytic converter, oxidizing or burning takes place. The temperature of this secondary combustion is approximately 200°F (92.4°C) higher than the temperature of the exhaust gases entering the converter. If the exhaust gas is 1200°F (648°C) when it enters the converter, it will begin

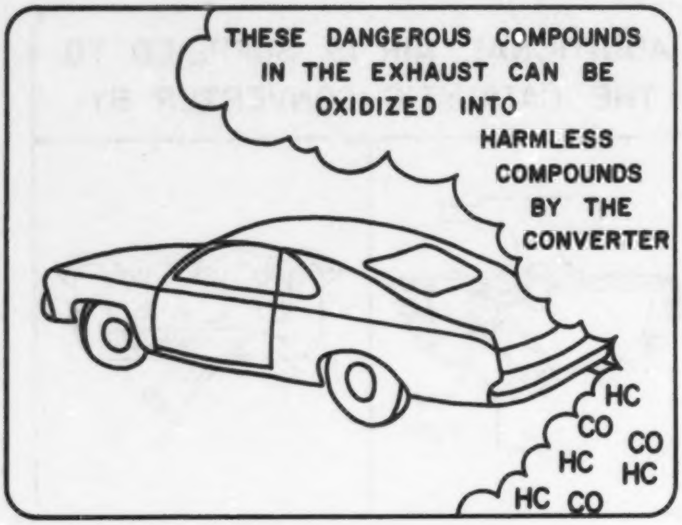

THESE DANGEROUS COMPOUNDS IN THE EXHAUST CAN BE OXIDIZED INTO HARMLESS COMPOUNDS BY THE CONVERTER
HC
CO
CO
HC
HC
HC
CO

FIGURE 8-11

to burn or oxidize and raise the temperature to approximately 1400°F (752.4°C) in the converter (Figure 8-12).

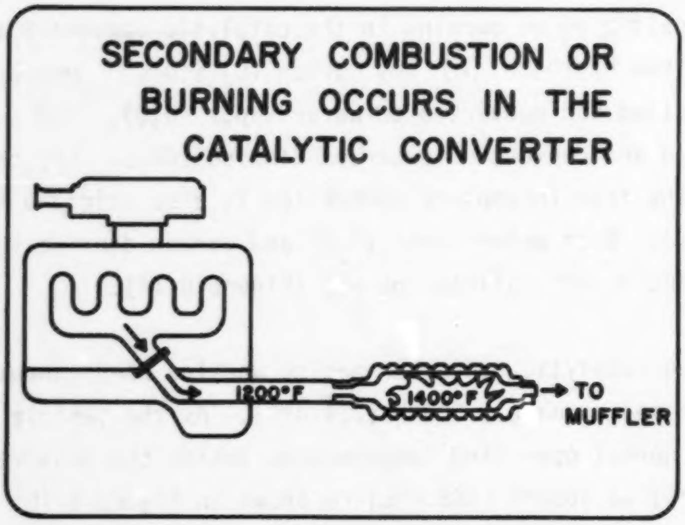

SECONDARY COMBUSTION OR BURNING OCCURS IN THE CATALYTIC CONVERTER
1200°F
1400°F
TO MUFFLER

FIGURE 8-12

Additional air is supplied to the catalytic converter (Figure 8-13) for the burning or oxidizing process by two means: an AIR pump, which pumps

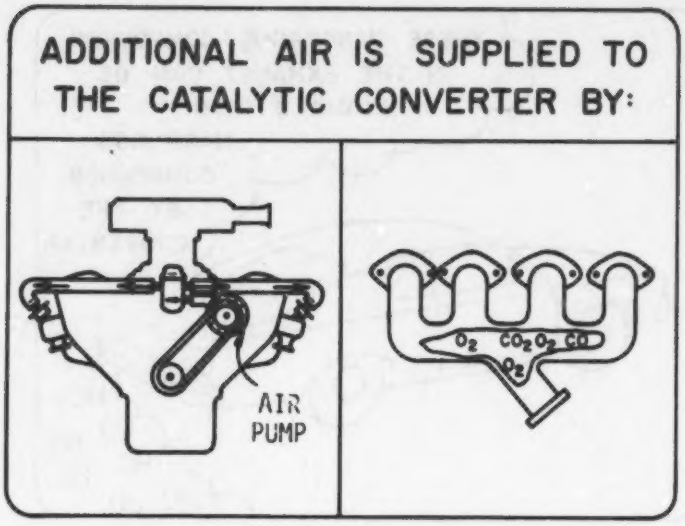


FIGURE 8-13

air into the exhaust manifold, and excessive air in the exhaust manifold that has not been used in the combustion process.

During the oxidizing or burning in the catalytic converter the hydrocarbons are broken into hydrogen (H) and carbon (C) atoms. The hydrogen (H) is then oxidized and converted to water vapor (H_2O). The carbon (C) is also oxidized and converted to carbon dioxide (CO_2). Any carbon monoxide (CO) resulting from incomplete combustion is also oxidized to carbon dioxide (CO_2). Both water vapor (H_2O) and carbon dioxide (CO_2) are harmless gases and do not pollute the air (Figure 8-14).

The oxidizing catalytic converter begins working when exhaust gas temperatures reach approximately 500°F (254.4°C). As the vehicle is being driven, the normal operating temperatures inside the converter will be 1200°F (648°C) to 1600°F (862.4°C) as shown in Figure 8-15. During these operating conditions, the outside stainless steel shell temperatures will be approximately 600-800°F (312-422°C).

Much higher temperatures can occur in the converter. These higher temperatures can be caused by one or more spark plugs misfiring or a carburetor

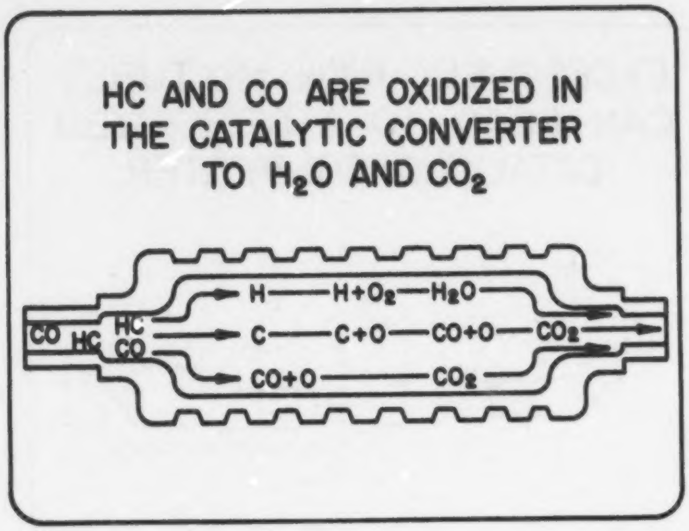

HC AND CO ARE OXIDIZED IN THE CATALYTIC CONVERTER TO H_2O AND CO_2
CO
HC
HC
CO
H
$H+O_2$
H_2O
C
C+O
CO+O
CO_2
CO+O
CO_2

FIGURE 8-14

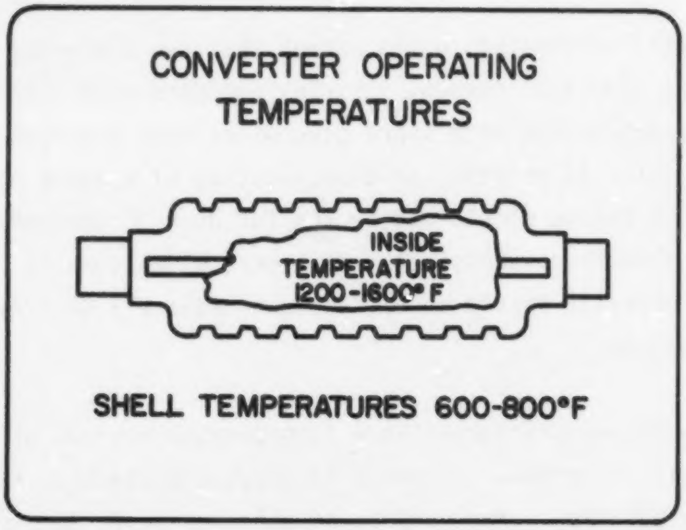

CONVERTER OPERATING TEMPERATURES
INSIDE TEMPERATURE 1200-1600° F
SHELL TEMPERATURES 600-800°F

FIGURE 8-15

malfunction that allows an excessively rich mixture (Figure 8-16). If either of these conditions occur, an increased burning or oxidation will occur. This increase in oxidation rate will lead to a rapid increase in temperature. If this temperature reaches approximately 2500°F (1357°C), the aluminum oxide pellets or the aluminum substrate in the monolith

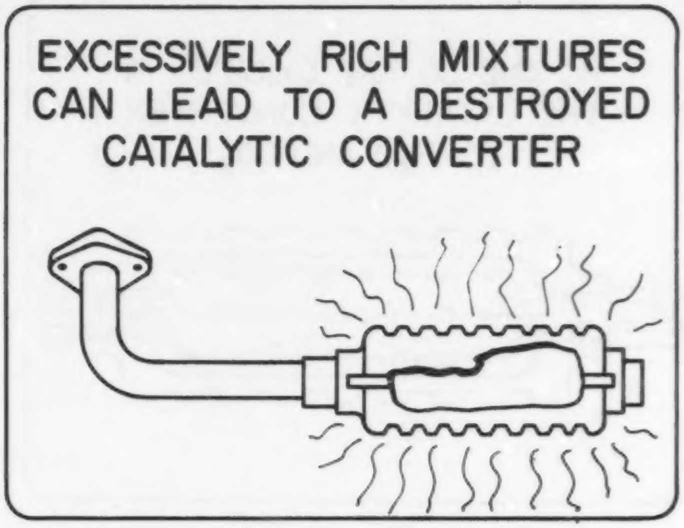


FIGURE 8-16

converter will be damaged to the extent that the converter will have to be replaced. For this reason, vehicles equipped with catalytic converters should not be run with spark plug wires that are open, disconnected or shorted out. If shorting or disconnecting of a spark plug is required, the engine should not be run for over 30 seconds. Any condition which allows an excessively rich air/fuel mixture to reach the catalytic converter should be corrected immediately to prevent possible converter damage.

Some automobile manufacturers have incorporated methods of protecting the catalytic converter. Figure 8-17 shows a protection system used by Chrysler Corporation. The purpose of this system is to protect the catalytic converter from overheating and damage during periods of deceleration. When engine speed exceeds 2000 RPM, the throttle position solenoid is energized by a signal from the electronic speed switch. When the throttle is released, the throttle position solenoid holds the throttle at a preset point corresponding to 1500 RPM. The electronic speed switch senses when engine speed drops below 2000 RPM and de-energizes the throttle position solenoid allowing the throttle plates to return to the curb idle position. By keeping the throttle plates at a 1500 RPM

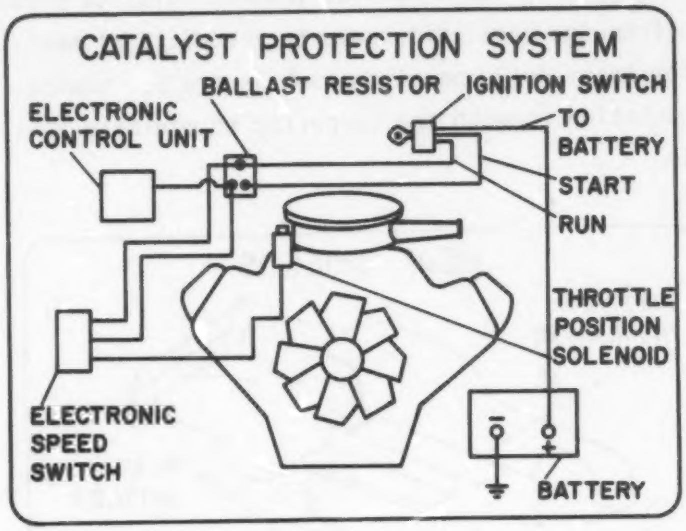

CATALYST PROTECTION SYSTEM
BALLAST RESISTOR
IGNITION SWITCH
ELECTRONIC CONTROL UNIT
TO BATTERY
START
RUN
THROTTLE POSITION SOLENOID
ELECTRONIC SPEED SWITCH
BATTERY

FIGURE 8-17

position, enough air is admitted during deceleration to allow more complete combustion and prevent excessive hydrocarbon buildup in the converter.

Shown in Figure 8-18 is Ford's Thermactor system that is used to pump additional air into the exhaust manifold. This additional air permits further oxidation or burning to occur in the exhaust manifold and also provides the necessary air for the proper operation of the catalytic converter.

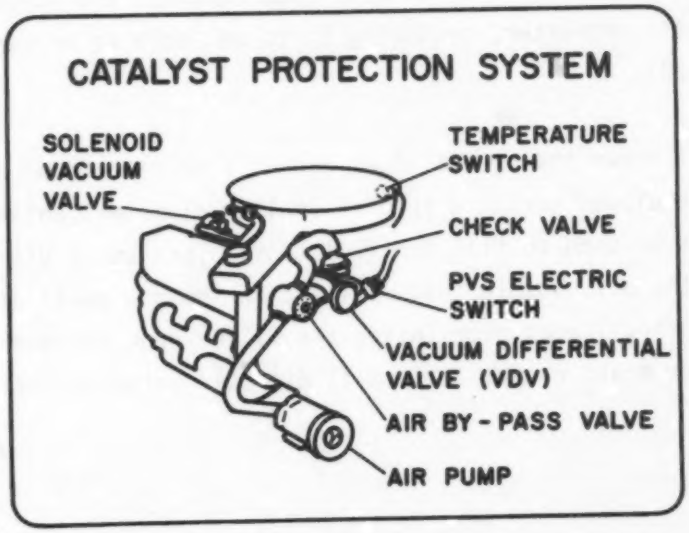

CATALYST PROTECTION SYSTEM
SOLENOID VACUUM VALVE
TEMPERATURE SWITCH
CHECK VALVE
PVS ELECTRIC SWITCH
VACUUM DIFFERENTIAL VALVE (VDV)
AIR BY-PASS VALVE
AIR PUMP

FIGURE 8-18

Some manufacturers use heat shields (Figure 8-19) to protect undercarriage components from the catalytic converter's additional heat. Vehicles intended for heavy duty operation, such as trailer towing, will also have special insulation beneath the carpeting to minimize heat buildup inside the vehicle.

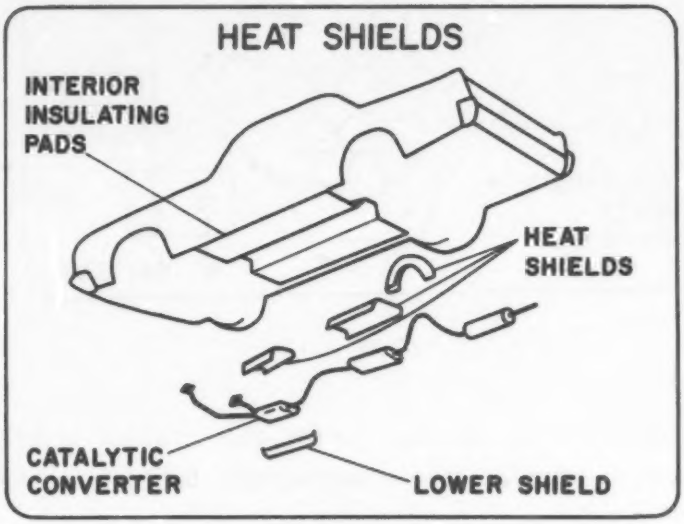


FIGURE 8-19

Any vehicle using a catalytic converter must use lead-free fuel. If leaded gasoline is used, the lead will coat the platinum-palladium catalyst material. This coating of lead destroys the effectiveness of the catalytic converter, requiring it to be replaced or recharged (Figure 8-20).

Figure 8-21 shows the special fuel tank filler neck found on all catalytic converter equipped cars. A special smaller diameter, unleaded fuel nozzle must be used to fill the fuel tank. This small diameter fuel nozzle is the only nozzle that will fit in the new small diameter filler neck. A spring loaded door inside the filler neck prevents adding fuel by any other means except this small diameter unleaded fuel nozzle.

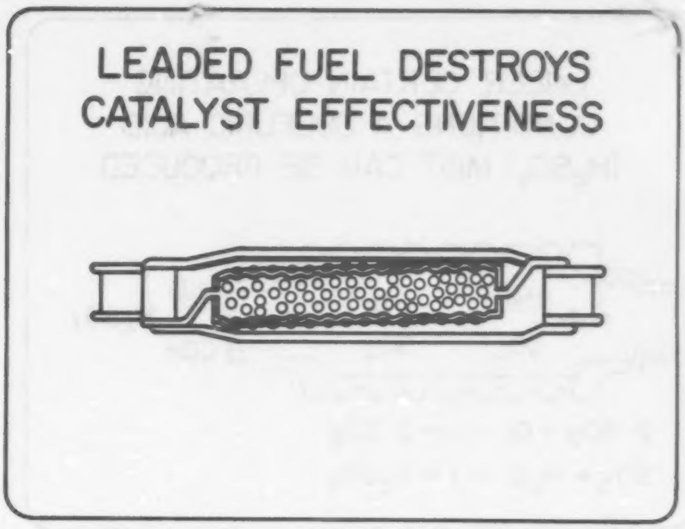

LEADED FUEL DESTROYS
CATALYST EFFECTIVENESS

FIGURE 8-20

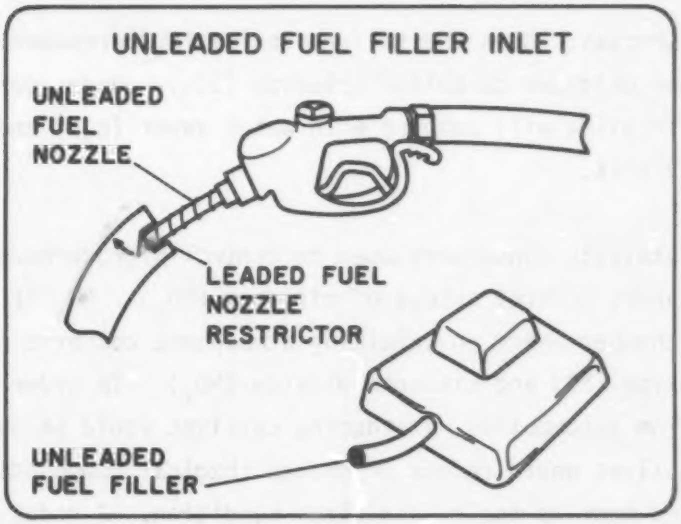

UNLEADED FUEL FILLER INLET
UNLEADED FUEL NOZZLE
LEADED FUEL NOZZLE RESTRICTOR
UNLEADED FUEL FILLER

FIGURE 8-21

One problem associated with catalytic converters is the production of a sulfuric acid (H_2SO_4) mist (Figure 8-22). Under certain operating conditions, the oxidizing atmosphere of the converter enhances the production of sulfuric acid. Sulfur is normally found in gasoline in very small quantities. The sulfur (S) is converted to sulfur dioxide (SO_2) in the

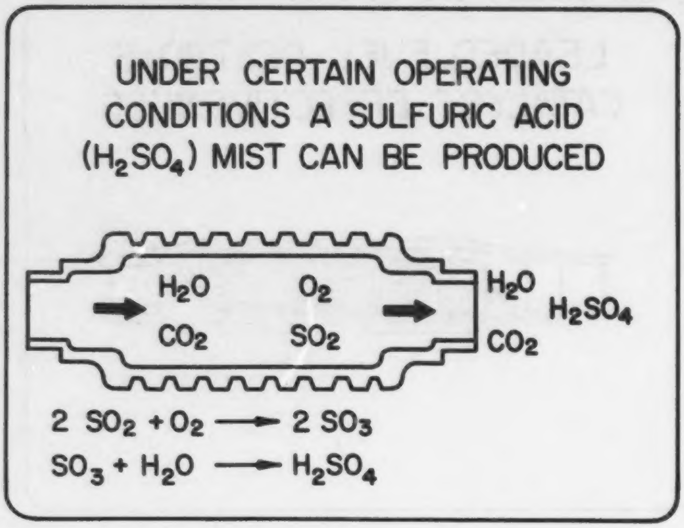

UNDER CERTAIN OPERATING CONDITIONS A SULFURIC ACID (H_2SO_4) MIST CAN BE PRODUCED
H_2O
O_2
CO_2
SO_2
H_2O
H_2SO_4
CO_2
$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$
$SO_3 + H_2O \longrightarrow H_2SO_4$

FIGURE 8-22

combustion process. When the sulfur dioxide (SO_2) reaches the converter, it is further oxidized to sulfur trioxide (SO_3). Under certain conditions the sulfur trioxide will combine with water vapor (H_2O) and form sulfuric acid (H_2SO_4) mist.

Oxidizing catalytic converters used to control hydrocarbons and carbon monoxide, cannot control oxides of nitrogen (NO_x). NO_x is formed in the combustion chamber where an oxidizing atmosphere converts nitrogen (N) to nitric oxide (NO) and nitrogen dioxide (NO_2). In order to control NO_x emissions from automobiles, a reducing catalyst would be needed. A reducing catalyst would reduce or change chemical compounds that have been oxidized back to their unoxidized condition. A reducing catalyst will convert NO and NO_2 back to nitrogen (N) and oxygen (O_2) both of which are harmless (Figure 8-23).

Remember - the purpose of the catalytic converter system is to reduce exhaust emissions by oxidizing hydrocarbons and carbon monoxide into harmless gases.

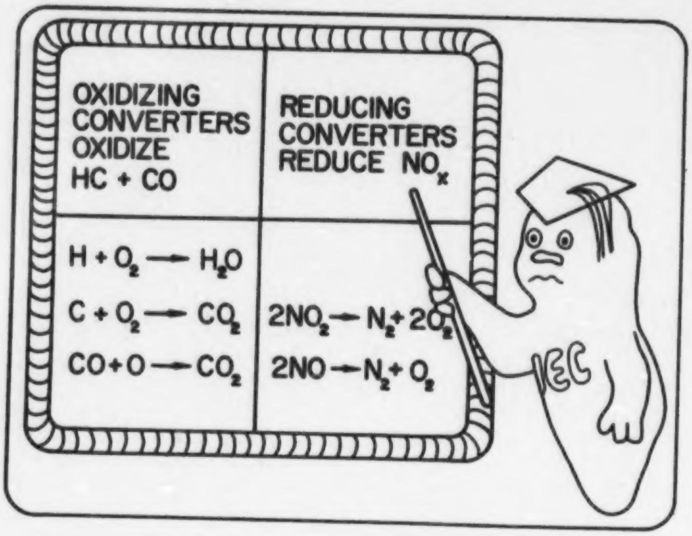

OXIDIZING CONVERTERS OXIDIZE HC + CO
REDUCING CONVERTERS REDUCE NO_x
$H + O_2 \rightarrow H_2O$
$C + O_2 \rightarrow CO_2$
$CO + O \rightarrow CO_2$
$2NO_2 \rightarrow N_2 + 2O_2$
$2NO \rightarrow N_2 + O_2$
IEC

FIGURE 8-23

CHAPTER 9

THE NONDISPERSIVE INFRARED ANALYZER AND ITS USE

INFRARED EXHAUST GAS ANALYZER

- Background Information -

The infrared exhaust gas analyzer is a piece of test equipment used to measure hydrocarbons and carbon monoxide. The infrared analyzer provides a hydrocarbon reading in parts per million (PPM). (One (1) part per million is equivalent to 1 second in 11.5 days.) Carbon monoxide readings are given in percent (%). Normally the hydrocarbon meter and the carbon monoxide meter have two scales -- a high scale and a low scale. Either scale can be selected by pressing the appropriate button or shifting a selector switch. The infrared analyzer can provide much valuable information for vehicle emissions inspection and diagnostic work. However, to utilize the infrared in this manner requires an understanding of hydrocarbons (HC) and carbon monoxide (CO). It may be necessary at this point to review Chapter One where emissions are covered. Hydrocarbons are unburned fuel. There is always a small portion of gasoline that does not burn. The hydrocarbon meter shows how much unburned fuel is being exhausted. Carbon monoxide is a product of incomplete burning. If too much fuel is present for the amount of air present, the CO meter will show a large amount of carbon monoxide being exhausted to the atmosphere. Understanding HC, CO and the correct use of the infrared exhaust gas analyzer is necessary to perform proper emissions inspections and provide meaningful informtion to the automobile owner as questions arise.

Figure 9-1 shows the basic parts of an infrared exhaust gas analyzer. This is provided to give a reference of basic theory of construction of an analyzer. Normally manufacturers of analyzers provide more in-depth information on the specific analyzer which the inspector will be using.

The basic parts of an infrared exhaust gas analyzer are:

1) Infrared Heater - Provides a constant source of infrared waves or energy through the reference and sample cells.
2) Chopper Wheel - A segmented disc driven by a motor. The disc constantly interrupts the infrared signal. This provides a pulsating infrared signal.

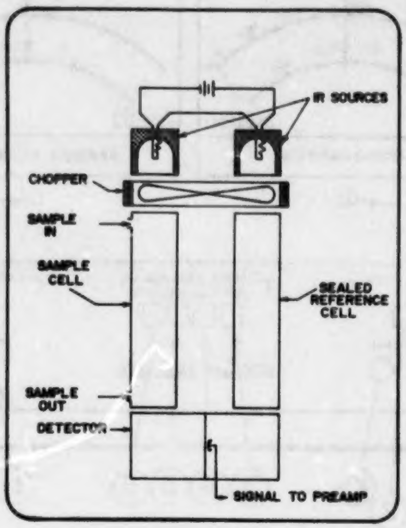

IR SOURCES
CHOPPER
SAMPLE IN
SAMPLE CELL
SEALED REFERENCE CELL
SAMPLE OUT
DETECTOR
SIGNAL TO PREAMP

FIGURE 9-1

3) **Sample Cell** - A cell that the exhaust gases flow through. Infrared or energy is absorbed as HC and CO pass through the sample cell.

4) **Reference Cell** - A cell that contains no HC or CO. No infrared waves or energy is absorbed in this cell.

5) **Detector** - Changes the infrared signal to an electrical signal.

6) **Amplifier** - Increases the electrical signal from the detector to provide meter readings.

Figure 9-2 shows a picture of the front of a typical analyzer. Although the different analyzers vary somewhat, the following is representative of basic meters and controls.

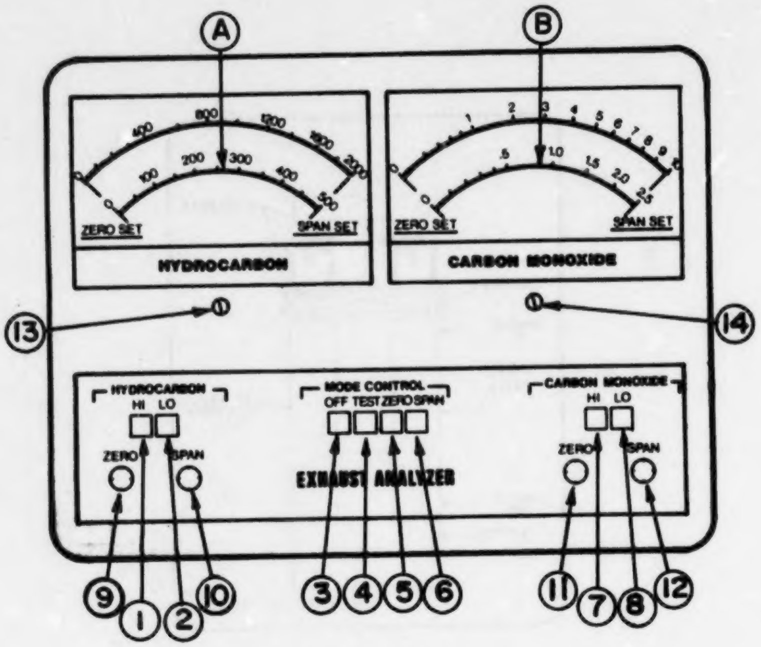

A
B
0
400
800
1200
1600
2000
0
100
200
300
400
500
ZERO SET
SPAN SET
HYDROCARBON
0
1
2
3
4
5
6
7
8
9
10
0
.5
1.0
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
13
14
HYDROCARBON
HI
LO
ZERO
SPAN
MODE CONTROL
OFF
TEST
ZERO
SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI
LO
ZERO
SPAN
9
1
2
10
3
4
5
6
11
7
8
12

FIGURE 9-2

TYPICAL METERS AND CONTROLS

Meters

A. Hydrocarbon meter

B. Carbon Monoxide meter

Hydrocarbon-Push Buttons

1. "HI" sets HC meter to read on the 0-2000 PPM scale.
2. "LO" sets HC meter to read on the 0-500 PPM scale.

Mode Control-Push Buttons

3. "OFF" - Turns tester off.
4. "TEST" - Turns tester on in test mode.
5. "ZERO" - Turns tester on to calibration and standby mode.
6. "SPAN" - Depress and hold while adjusting meters to "SPAN SET" line.

Carbon Monoxide-Push Buttons

7. "HI" sets CO meter to read on the 0-10% scale.
8. "LO" sets CO meter to read on the 0-2.5% scale

Rotating Controls

9. "ZERO" - Sets HC meter to Zero set line.
10. "SPAN" - Sets HC meter to Span set line.
11. "ZERO" - Sets CO meter to Zero set line.
12. "SPAN" - Sets CO meter to Span set line.

Meter Mechanical Zero

13. Adjusts Mechanical Zero of HC Meter.
14. Adjusts Mechanical Zero of CO Meter.

Exhaust gas samples are continuously delivered to the infrared analyzer by means of a probe inserted in the vehicle's tailpipe (Figure 9-3). The exhaust gas is then filtered and the water is removed before being conducted into the infrared analyzing device. The infrared analyzing device determines the exact amount of hydrocarbons and carbon monoxide contained in the sample. This data is then converted into electrical signals and displayed on the respective meters.

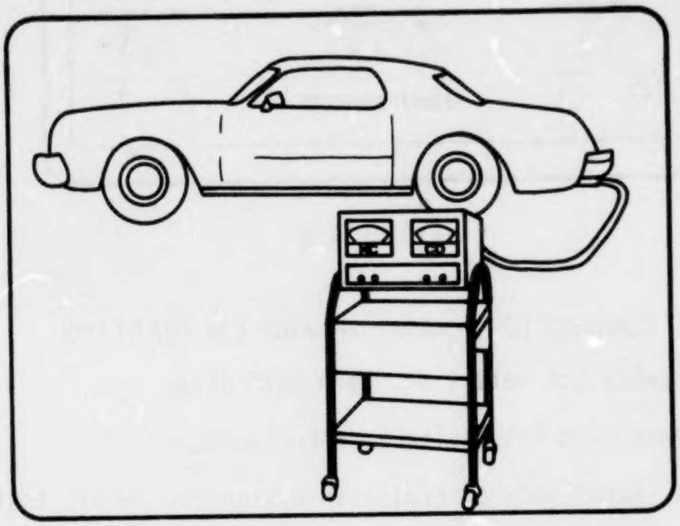
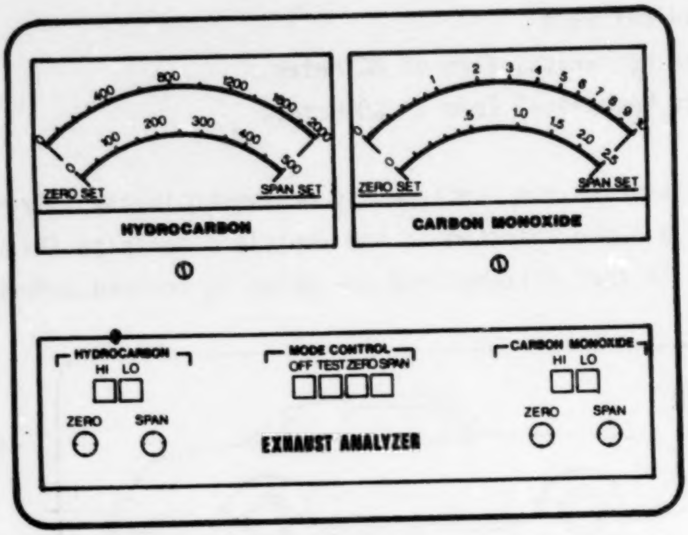


FIGURE 9-3

Before any testing can be done certain precautions must be taken to make sure the tests made are valid. The analyzer must be warmed up and prepared for use. Always follow the manufacturer's specifications and recommendations in preparing the analyzer for use. Although the different analyzers vary somewhat, the following is a basic procedure for preparing most infrared exhaust analyzers for use. Refer to Figure 9-4 as you read through this procedure.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1600
2000
0
100
200
300
400
500
ZERO SET
SPAN SET
HYDROCARBON
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1
2
3
4
5
6
7
8
9
10
0
.5
1.0
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI
LO
ZERO
SPAN
MODE CONTROL
OFF
TEST
ZERO
SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI
LO
ZERO
SPAN

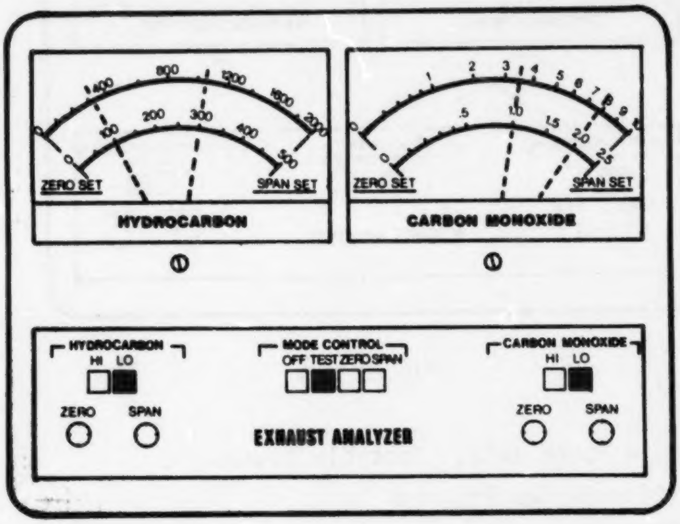
FIGURE 9-4

CONNECTION, WARM-UP AND CALIBRATION

1. Mechanically set meters to "Zero Set" line.
2. Plug power cord into suitable receptable.
3. Depress "Zero" mode control push button and permit tester to operate for approximately 5 mintues.
4. Depress "LO" button for each meter
5. Zero the Hydrocarbon meter, if necessary, by rotating the Hydrocarbon meter zero adjust knob until the Hydrocarbon meter pointer reads on its "Zero Set" line.
6. Zero the Carbon Monoxide meter, if necessary, by rotating the Carbon Monoxide zero adjust knob until the Carbon Monoxide meter pointer reads on its "Zero Set" line.
7. Depress and hold the "Span" mode control push button and, if necessary, rotate the span adjust knob until corresponding meters read on their respective "Span Set" lines.
8. Release "Span" push button and recheck zero adjustment of both meters.

METER READINGS AND PROBABLE MALFUNCTIONS

The following illustrations are provided to associate meter readings with probable malfunctions that can be typically diagnosed with the use of the infrared gas analyzer. The first illustration indicates a normal range of reading on the meters. The high or low switch for hydrocarbons and carbon monoxides will be darkened to illustrate the scale selection of each meter.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400
500
ZERO SET
SPAN SET
HYDROCARBON
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2
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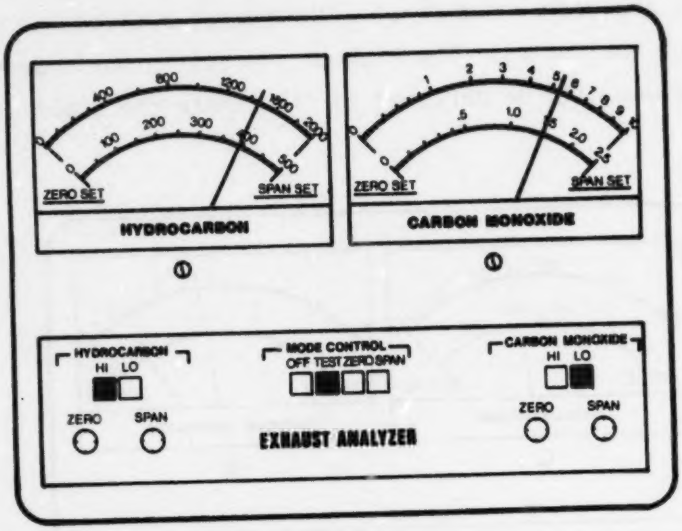
4
5
6
7
8
9
10
0
.5
1.0
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI LO
ZERO
SPAN
MODE CONTROL
OFF TEST ZERO SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI LO
ZERO
SPAN

FIGURE 9-5

1. With the engine at operating temperature and idling, Figure 9-5 shows a "normal" reading.

   NOTE: "Normal" readings vary from car to car. The normal readings shown here do not apply to catalytic converter equipped cars.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ZERO SET
SPAN SET
HYDROCARBON
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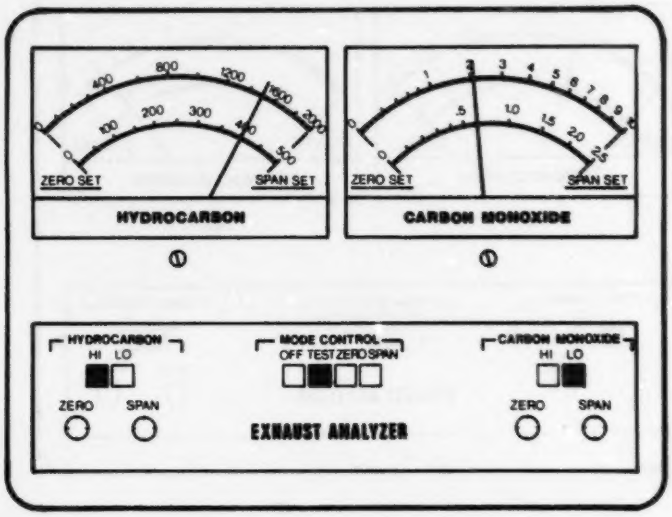
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI LO
ZERO
SPAN
MODE CONTROL
OFF TEST ZERO SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI LO
ZERO
SPAN

FIGURE 9-6

2. Symptoms - Rough Idle. Possible causes:
   a) Ignition System Problem
      1) Timing too far advanced
      2) Fouled or shorted spark plug
      3) Open or grounded spark plug wire
      4) Crossed spark plug wires
      5) Leaking valves
      6) Leaking EGR valve
      7) Primary ignition system problem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ZERO SET
SPAN SET
HYDROCARBON
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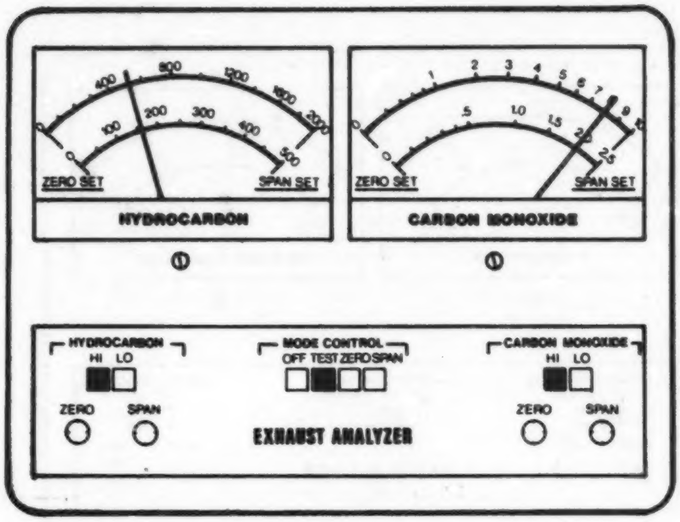
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI LO
ZERO
SPAN
MODE CONTROL
OFF TEST ZERO SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI LO
ZERO
SPAN

FIGURE 9-7

3. Symptoms - Rough idle.
   - a) Lean misfire
     - 1) Idle mixture set too lean
     - 2) Wrong PCV valve or PCV valve stuck open
     - 3) Vacuum line cracked or pulled off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ZERO SET
SPAN SET
HYDROCARBON
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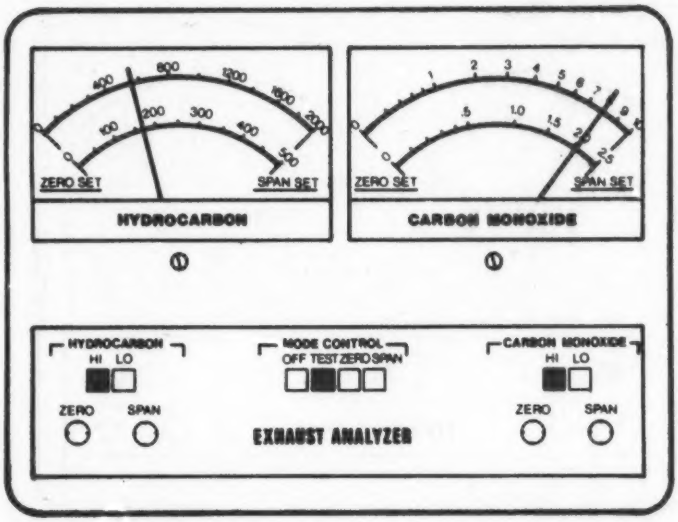
4
5
6
7
8
9
10
0
.5
1.0
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI
LO
ZERO
SPAN
MODE CONTROL
OFF
TEST
ZERO
SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI
LO
ZERO
SPAN

FIGURE 9-8

4. Symptoms - Rough idle.
   a) Carburetion problem
      1) Idle mixture set too rich
      2) Improper choke operation or setting
      3) Leaking power valve
      4) Float level too high
      5) Restricted air cleaner element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400
500
ZERO SET
SPAN SET
HYDROCARBON
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6
7
8
10
0
.5
1.0
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI LO
MODE CONTROL
OFF TEST ZERO SPAN
CARBON MONOXIDE
HI LO
ZERO
SPAN
EXHAUST ANALYZER
ZERO
SPAN

FIGURE 9-9

5. No rough idle
   a) Air injection system not working

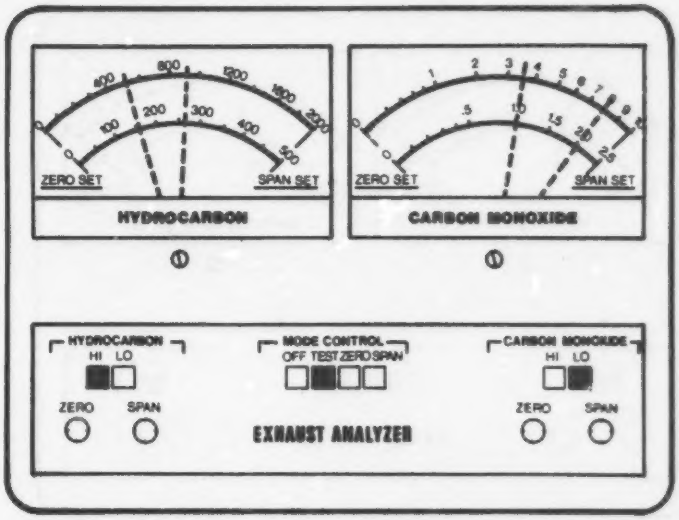
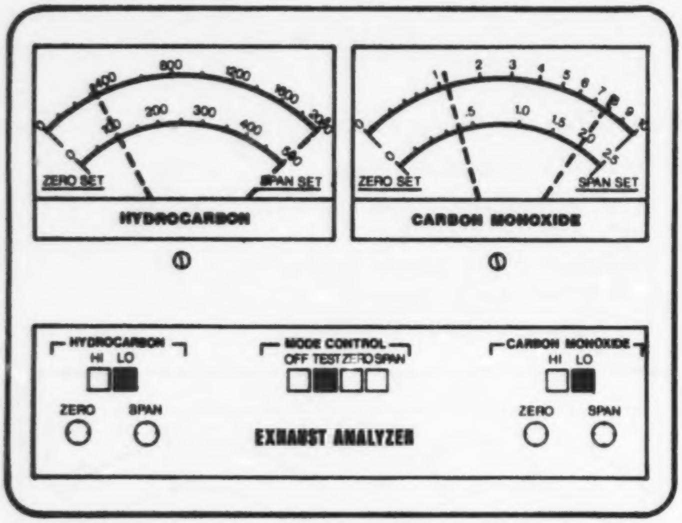

ZERO SET
SPAN SET
HYDROCARBON
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI LO
ZERO SPAN
MODE CONTROL
OFF TEST ZERO SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI LO
ZERO SPAN

FIGURE 9-10

6. Symptoms - Engine surging, 1500 RPM
   a) Erratic EGR valve operation
   b) Timing too far advanced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400
500
ZERO SET
SPAN SET
HYDROCARBON
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7
8
9
10
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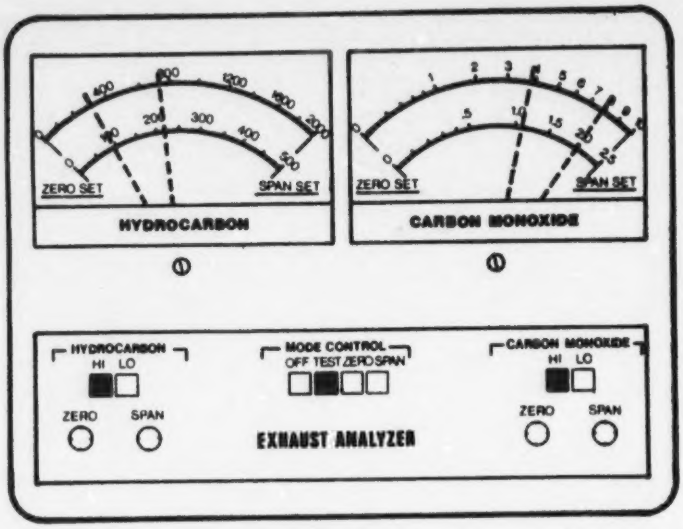
.5
1.0
1.5
2.0
2.5
ZERO SET
SPAN SET
CARBON MONOXIDE
HYDROCARBON
HI
LO
ZERO
SPAN
MODE CONTROL
OFF
TEST
ZERO
SPAN
EXHAUST ANALYZER
CARBON MONOXIDE
HI
LO
ZERO
SPAN

FIGURE 9-11

7. Symptoms - Engine surging, 1500 RPM
   a) Carburetion too lean



HYDROCARBON
CARBON MONOXIDE
ZERO SET
SPAN SET
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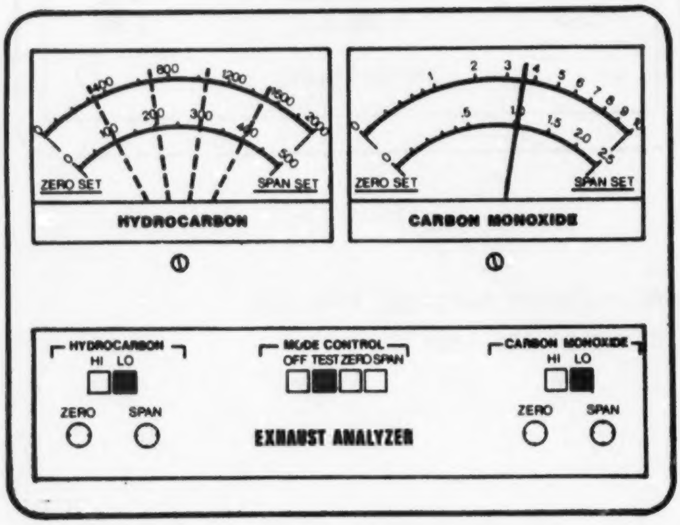
400
800
1200
1600
2000
100
200
300
400
500
1
2
3
4
5
6
7
8
9
10
.5
1.0
1.5
2.0
2.5
HYDROCARBON
HI LO
MODE CONTROL
OFF TEST ZERO SPAN
CARBON MONOXIDE
HI LO
ZERO
SPAN
EXHAUST ANALYZER

FIGURE 9-12

8. Symptoms - Possible black smoke, 2500 RPM
    a) Carburetion problems
        1) Main metering system too rich
        2) High float level
        3) Improper power valve operation
        4) Choke not fully open



HYDROCARBON
CARBON MONOXIDE
ZERO SET
SPAN SET
0
400
800
1200
1600
2000
100
200
300
400
500
1
2
3
4
5
6
7
8
9
10
.5
1.0
1.5
2.0
2.5
HYDROCARBON
HI LO
MODE CONTROL
OFF TEST ZERO SPAN
CARBON MONOXIDE
HI LO
ZERO
SPAN
EXHAUST ANALYZER

FIGURE 9-13

9. Symptoms - Occasional miss, 1500-2500 RPM
    a) Occasional ignition misfire
    b) Sticking valve(s)

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